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Title: ISOCS and SNAPTM

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National Nuclear Security Administration

OFFICE OF
NONPROLIFERATION AND ARMS CONTROL (NPAC)

ISOCS and SNAP™

Fundamentals of Nondestructive Assay for International Safeguards

Los Alamos National Laboratory

March 15-19, 2019

Steve Myers

LANL Retiree

LA-UR

SAFEGUARD NUCLEAR MATERIALS TO PREVENT THEIR DIVERSION OR THEFT

CONTROL THE SPREAD OF WMD-RELATED MATERIAL, EQUIPMENT AND TECHNOLOGY

NEGOTIATE, MONITOR AND VERIFY COMPLIANCE WITH INTERNATIONAL NONPROLIFERATION AND ARMS CONTROL TREATIES AND AGREEMENTS

DEVELOP PROGRAMS AND STRATEGIES TO ADDRESS EMERGING NONPROLIFERATION AND ARMS CONTROL THREATS AND CHALLENGES

ABSTRACT

- Students are taught the principles of ISOCS and SNAP™
- and their applications for measuring nuclear material
- Students will learn the applications for ISOCS and SNAP™
- Students will be able to describe the ISOCS analysis process
- Students will be able to describe the SNAP™ 4 step process
- Students will explain how ISOCS generates an efficiency curve
- Students will understand how to calculate a minimum detectable activity (MDA) in SNAP™ and ISOCS
- Students will know the corrections necessary to perform a simple assay estimate by hand calculation

Terminal Learning Objective

Participants will understand the principles of ISOCS and SNAP™ and their applications for measuring nuclear material

Enabling Learning Objective

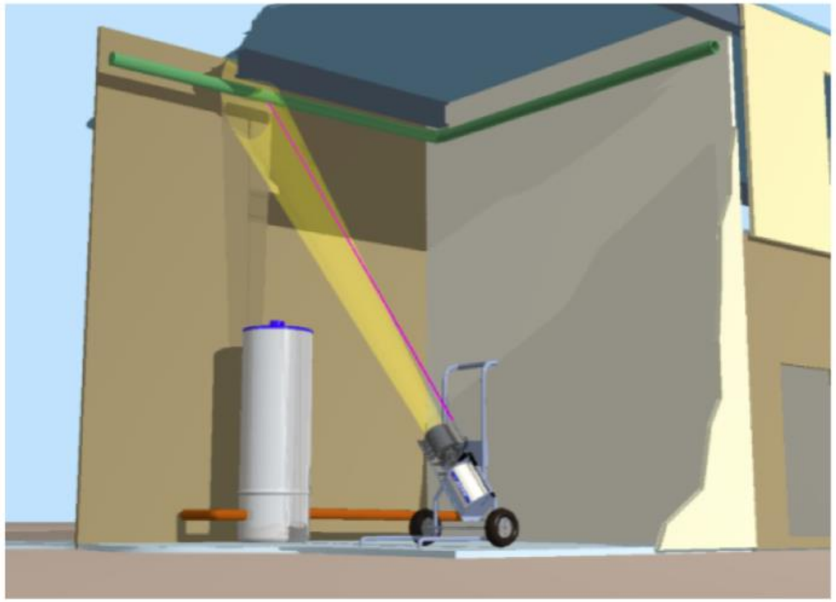
- Define ISOCS and SNAP™
- List applications for ISOCS and SNAP™
- Describe the ISOCS analysis process
- Describe the SNAP™ 4 step analysis process
- Explain how ISOCS generates an efficiency curve
- Understand how to calculate a minimum detectable activity (MDA) in SNAP™
- Know the corrections necessary to perform a simple assay estimate by hand calculation

What is ISOCS?

ISOCS = In-Situ Object Counting System

- Consists of software and characterized detectors from Canberra
- Determines absolute efficiency through mathematical modeling and knowledge of detector properties
- Used for quantification of nuclear and radiological material
  - Mass
  - Activity

ISOCS Applications



Applications where no calibration standard is available or practical to use

- Holdup
- Waste characterization
- Environmental characterization of radioactive contamination
- Many others, ISOCS is a very flexible method

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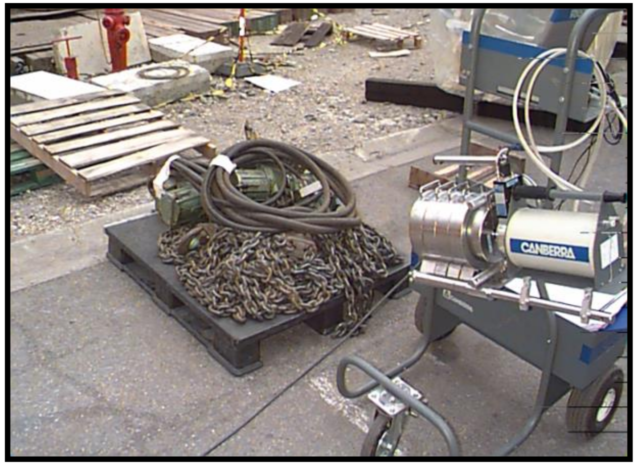
ISOCS Applications



ISOCS Measurement Process

- Characterizing detector at the factory
- Acquiring spectral data from the object
- Specifying the dimensions and physical composition of the measured object
- Generating an efficiency curve specific for the specified measurement configuration
- Using the efficiency curve to analyze the acquired spectra to calculate activity or mass

Traditional Definition of Efficiency

Efficiency of a detection system: defined as the detector's observed (measured) peak area count rate divided by the expected gamma emission rate for that gamma energy

$$Efficiency = \frac{number\ of\ photons\ registered\ by\ detector}{number\ of\ photons\ emitted\ by\ the\ source}$$

Efficiency Components

- Efficiency is specific to each particular measurement configuration and is dependent on a variety of factors
- Factors contributing to the full (absolute) efficiency:
  - Geometry of nuclear material (distance, shape, etc.)
  - Attenuation (container walls, absorbers, etc.)
  - Object self-attenuation (attenuation in nuclear material)
  - Intrinsic efficiency (efficiency of the detector crystal)

$$\varepsilon_{full} = \varepsilon_{geom} \cdot \varepsilon_{atten} \cdot \varepsilon_{self} \cdot \varepsilon_{int}$$

Classic Efficiency Calibration - Measured

- Well-characterized calibration source in fixed position from the detector
- Measure detector response to the known mass of material
- Calculate calibration coefficient

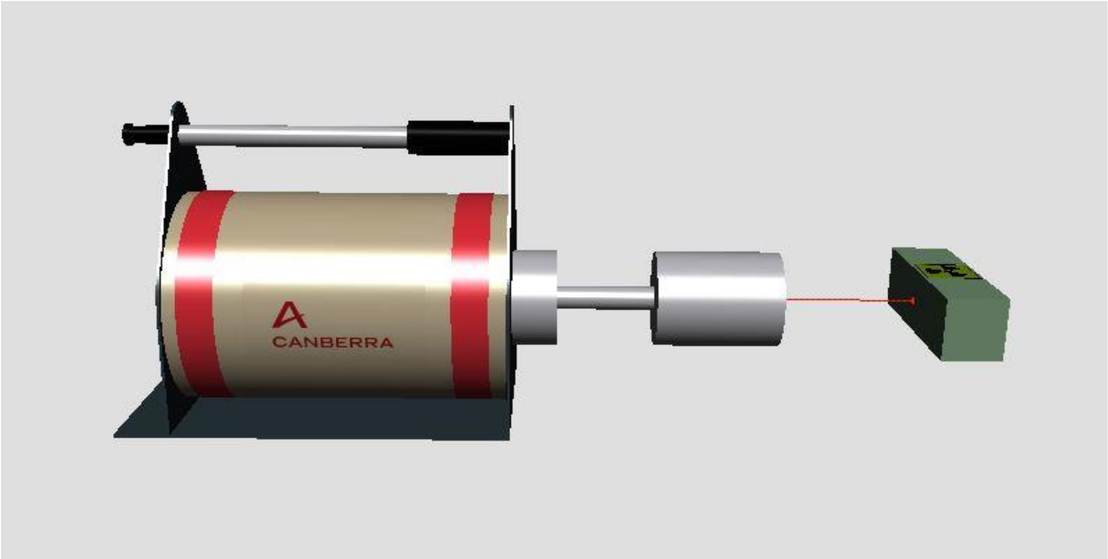
$$m = k \cdot CR$$

where

m – mass of the item

k – calibration coefficient

CR – count rate in the detector

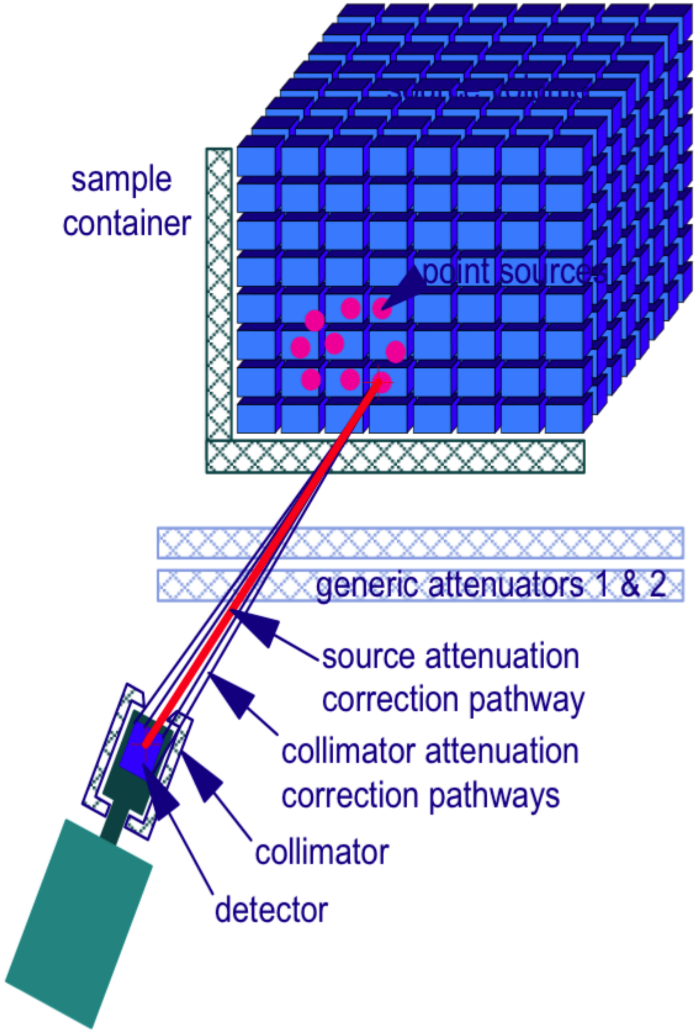


Note, this calibration is dependent on the source-to-detector distance and geometry of the nuclear material

ISOCS Efficiency Calibration - Calculated

ISOCS allows the determination of the absolute efficiency without using a calibration source

- Develop an MCNP model of the detector that reproduces a set of measurements collected at the factory
- Using this model and the MCNP code, generate a large lookup table that presents efficiency versus position versus energy for unattenuated point sources
  - This table is the “detector characterization” – it is customized for each detector



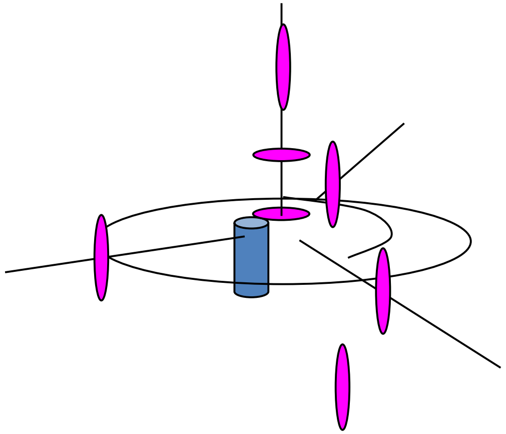
Detector Characterization

Performed at factory

- All HPGe detectors are unique
  - Detectors can be made with various diameter and height combinations
  - Variable dead-layer [front, sides, back]
- These parameters are not well known from the manufacturing process
- They cannot be determined by measuring a source
  - But we need to know them accurately
  - Use combination of manufacturing dimensions and multiple radiation measurements under carefully controlled conditions

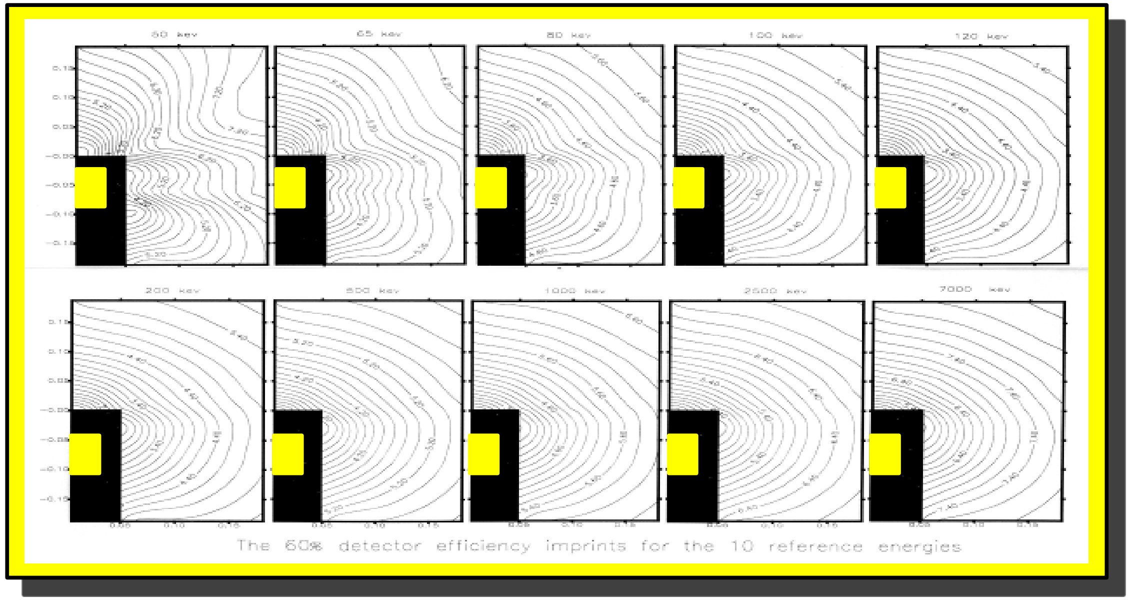
Detector Characterization – NM Measurements

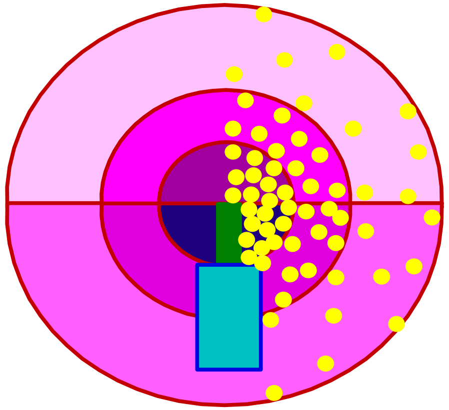
- NIST-traceable multi-energy sources
  - Point ^{241}Am, ^{152}Eu sources
  - Disc mixed gamma source
- Counted at 8 locations
  - Designed to determine important unknown detector parameters
- Use mechanical jig to assure precise geometry
- Use standardized factory electronics



Detector Characterization – Monte Carlo Modeling

- Detailed MCNP model of detector created
  - About 30 dimensional parameters
  - Populated by manufacturing dimensions
- Efficiency for each of the 8 source geometries computed with MCNP
  - Compared to measured efficiency
  - MCNP model key parameters adjusted so efficiency matches measured
    - Diameter, height, setback, dead layer [front, side, back]





Detector Characterization – Lookup Table

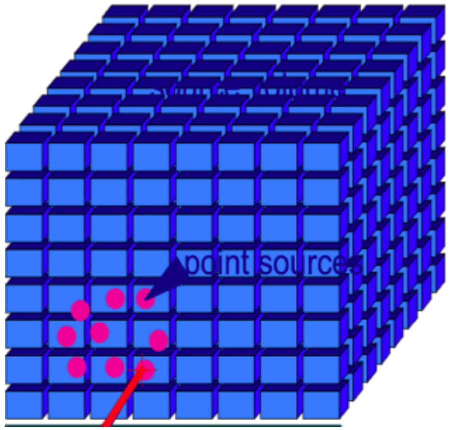
- Validated MCNP model used to compute efficiency at 800 spatial locations
  - High density where efficiency varies rapidly
  - Radial symmetry assumed
- Gridding process used to interpolate efficiency between modeled points
- Efficiency parameters incorporated into supplied Detector Characterization file used by ISOCS/LabSOCS software to create in-vacuo efficiency at each voxel point
  - 0 mm to 500 m distance
  - all directions - front, side, back
  - 45 keV - 7000 keV

ISOCS Efficiency Determination

ISOCS is a user-interface to an engine that evaluates a numerical integral

- Users specify the geometry (i.e. detector, container, materials)
- The ISOCS software breaks the radioactive portion of the geometry into “voxels”
  - Each voxel is treated as a point source
  - The efficiency for the point source is obtained from the characterization file (i.e. lookup table) modified by attenuation through all materials between the source and the detector

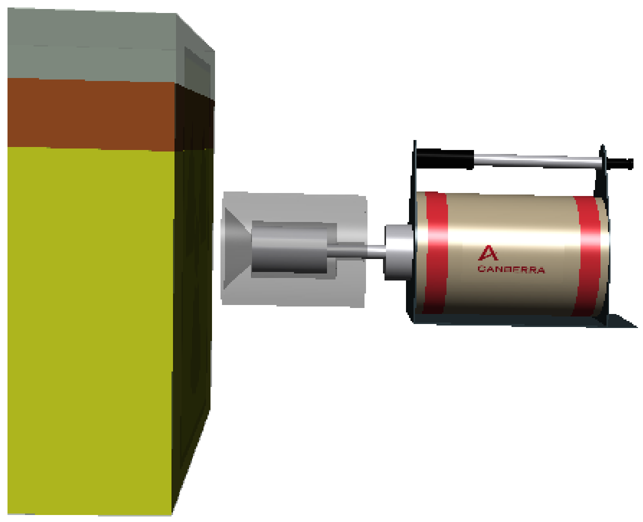
$$\varepsilon_{ISOCS} = \sum_{voxels} \varepsilon_{character.pt} \cdot attenuation$$

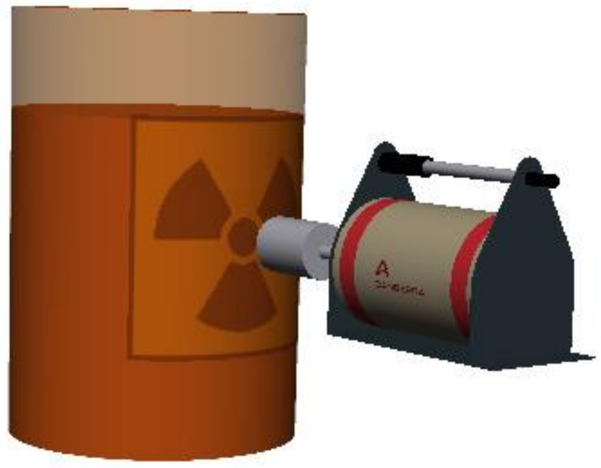


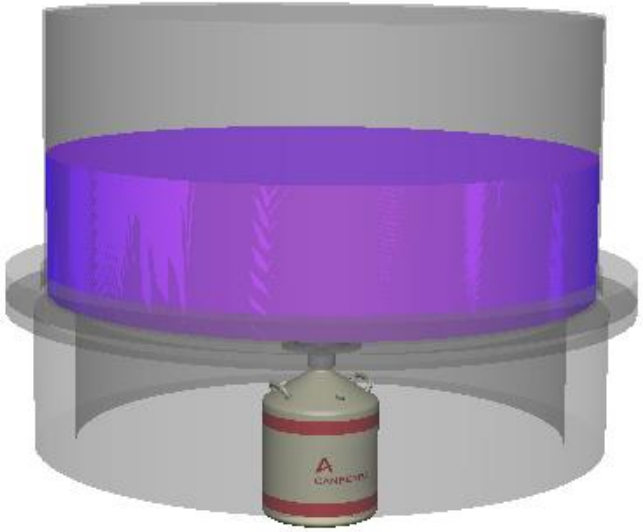
Hardware Configuration

- ISOCS is traditionally used with HPGe detectors
  - Factory characterized (specific characterization)
  - Regular detector (generic characterization)
- NaI detector characterizations are also available
- Multi-channel analyzer
- Computer with Genie-2000 software

ISOCS Models





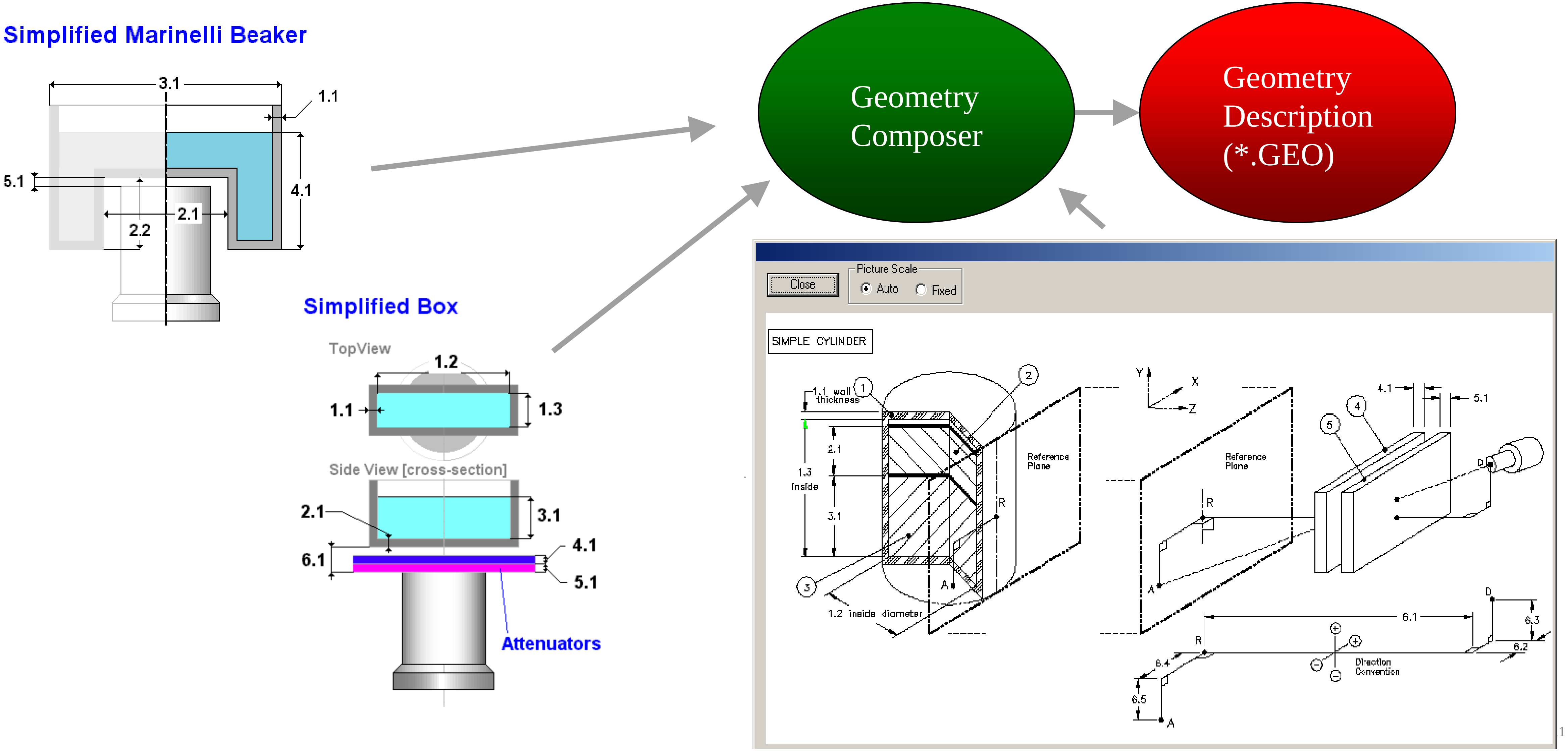


Almost any object likely to be encountered in the laboratory or the field can be adequately modeled using one of the ISOCS standard geometry templates

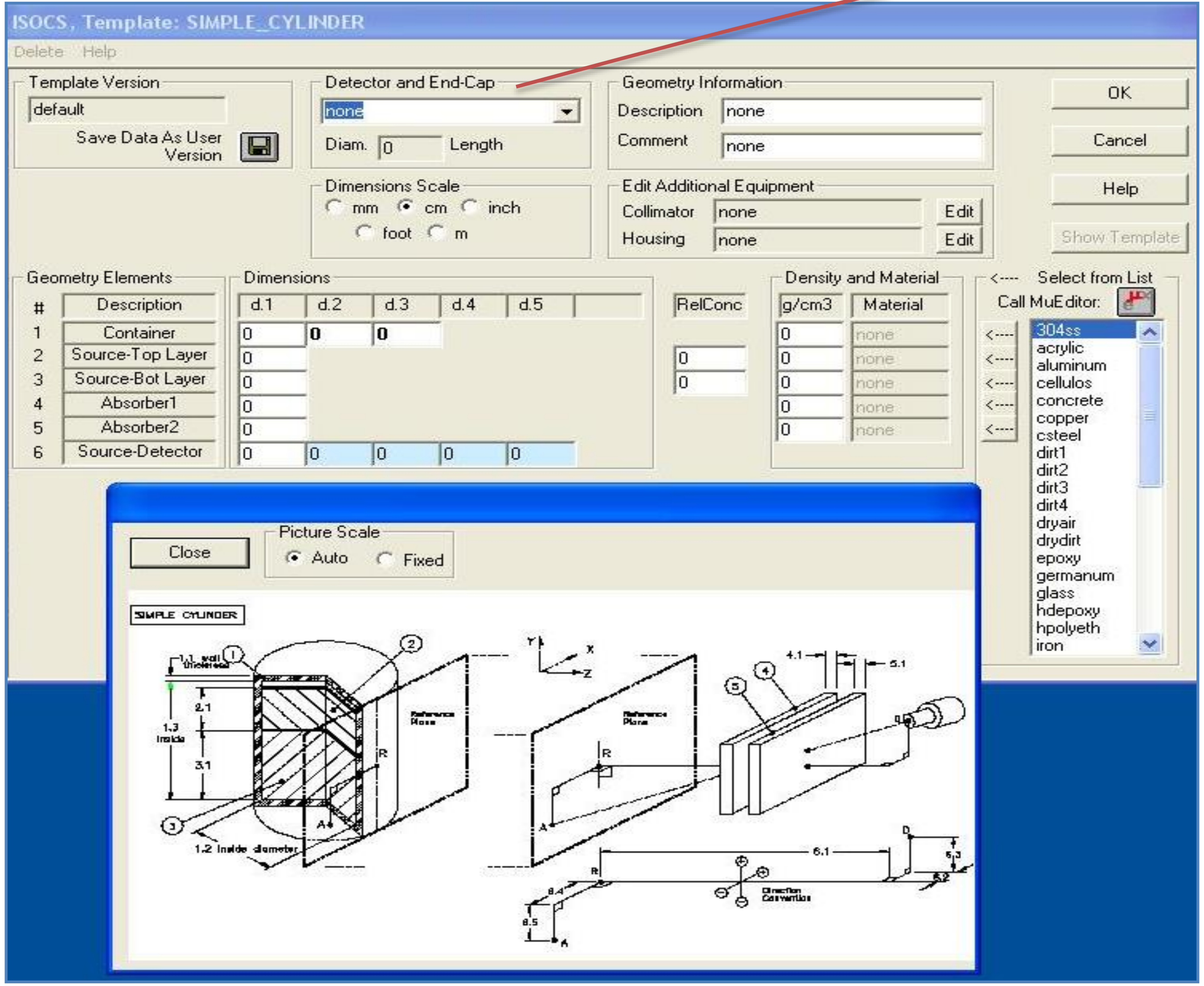
Using ISOCS Templates

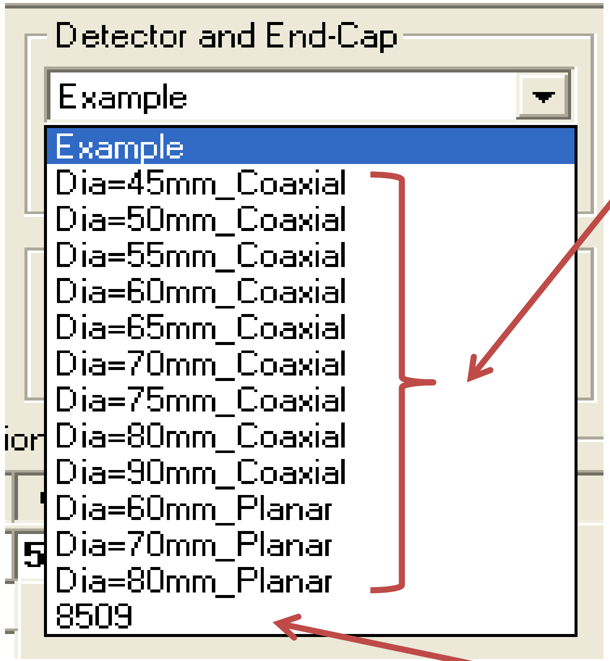
- Each template has a worksheet where operator can specify necessary physical dimensions of the object
- Each template has a reference plane and reference point that allows to specify detector position relative to the object
- Environmental conditions are important for lower energies and long distances
- Chemical composition and densities of the container and matrix must be specified

Geometry Description



Inputting Parameters





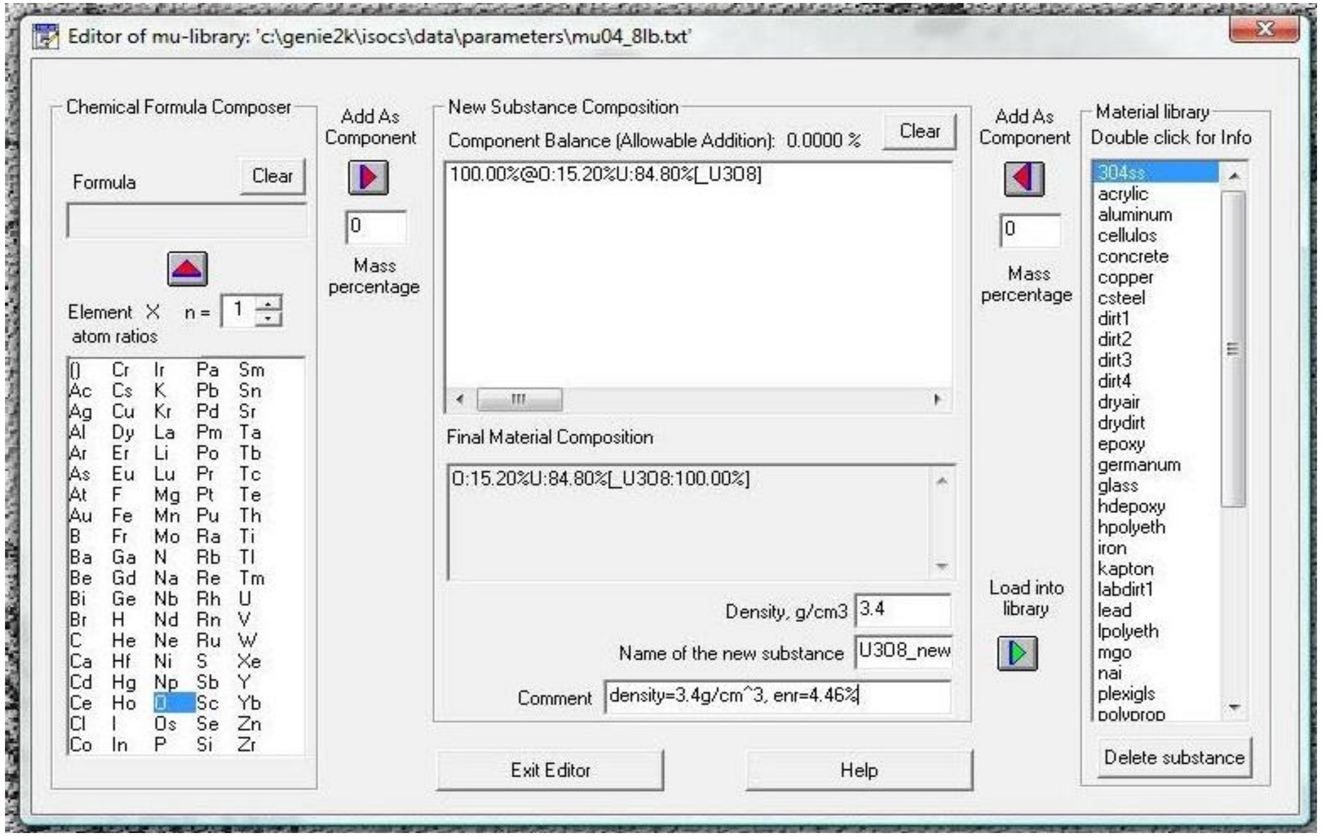
Generic Detector Characterizations

Detector with serial number 8509

Mu-Library Editor

Mu-library contains a variety of materials and compounds

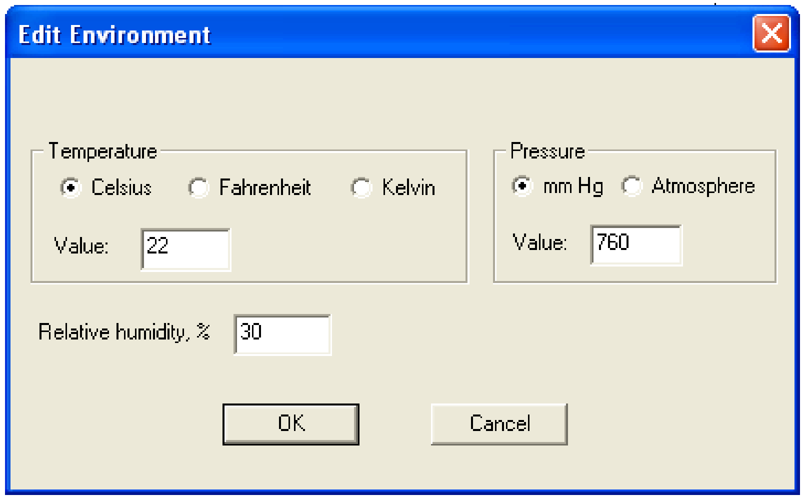
- Additional materials can be created and added

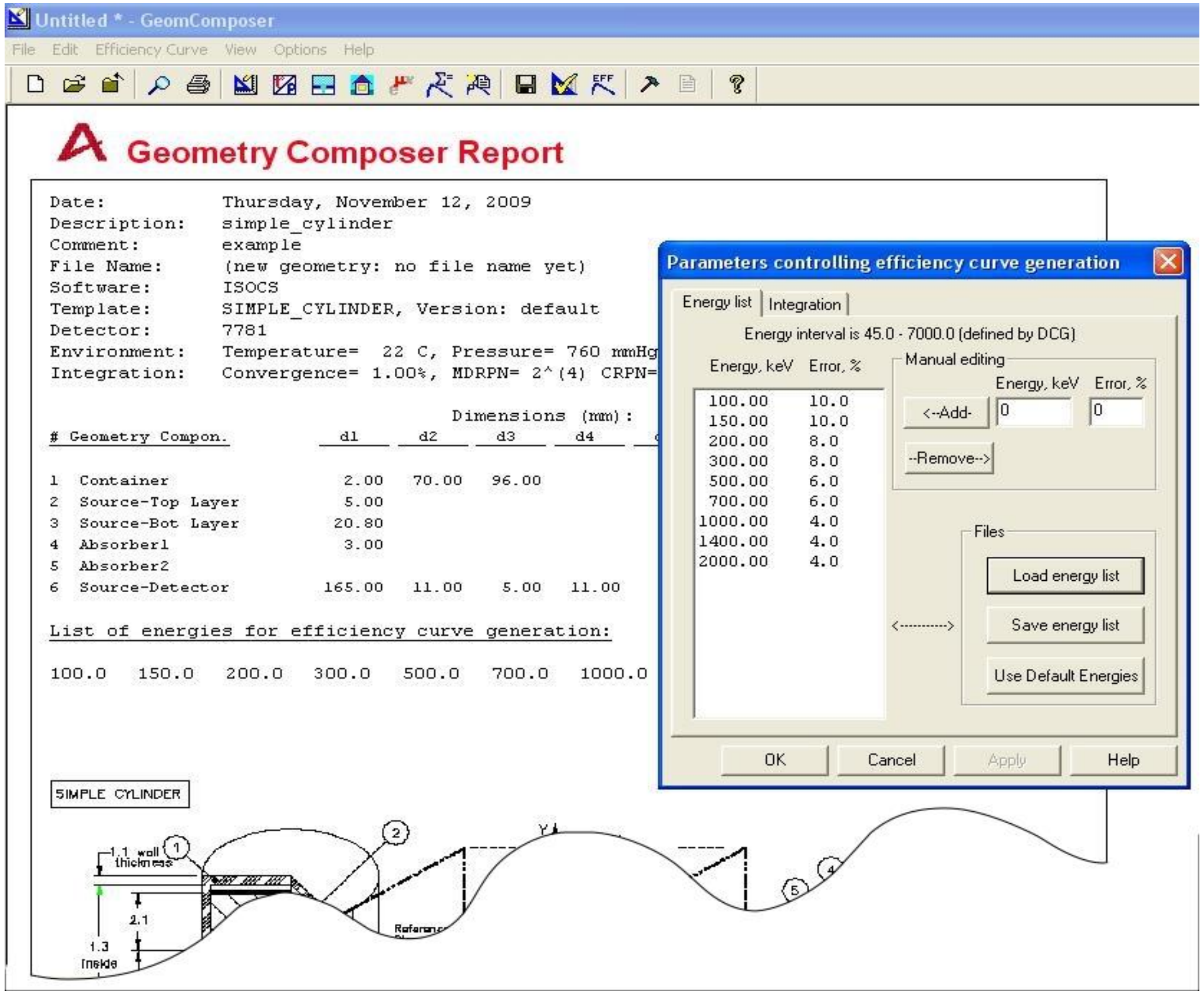


Geometry Composer Report

Once model is complete:

- Check geometry validity
- Verify efficiency parameters
- Adjust environmental conditions

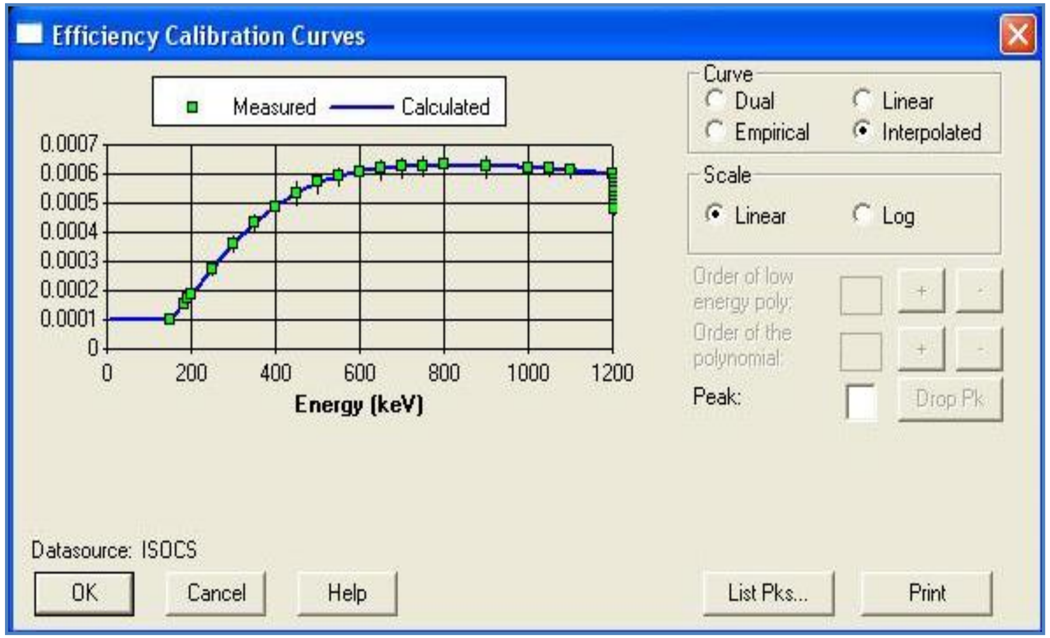


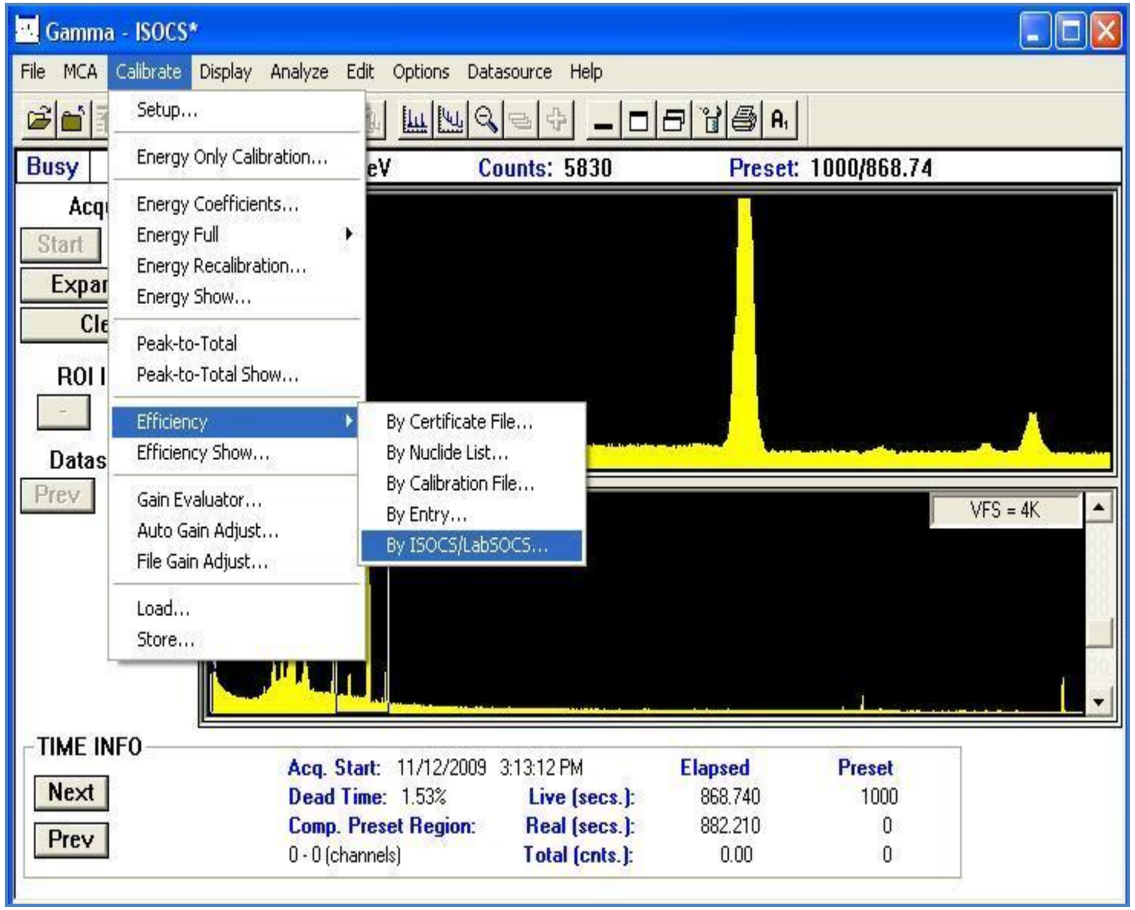


Efficiency Calibration in Genie

Next step is generating efficiency calibration curve in Genie-2000 software

- Choose curve type
- Store efficiency calibration file





Creating a Report

- Variety of reporting options available
  - Genie-2000 allows for creating custom reports or modifying existing
- Example of the report showing both activity and mass of nuclear material

File: ISOCS
NID Library: C:\GENIE2K\CAMFILES\U_only_shurus.NLB
Efficiency Calibration: SIMPLE_EXAMPLE

Sample ID: Sample title. **Operator:**_______________
Analysis performed: 11/12/09 3:33:42

No	Isotope	Activity, uCi	Mass, Gram	Uncertainty, %	Comment
1	U-235	20.14	9.59	0.49	
2	U-238	55.67	165.91	0.95	

Analyzed by:_________________________ **Reviewed by:**_________________________

ISOCS Performance

The accuracy of ISOCS will be dependent on

- How well known the geometry and composition of the NM is
- How well known the geometry and composition of interviewing material is
- How closely the modeled geometry matches the measurement configuration

For large quantities of NM material that are self attenuating, ISOCS can only confirm the material that can be seen

ISOCS Summary

- ISOCS is a sophisticated system for mathematical efficiency calibration and quantification of radioactive material
  - No calibration source required
  - Capabilities limited to the number of templates
- ISOCS can be used for many problems, from characterization of small samples in the laboratory, to process holdup in facility, to waste containers, to environmental surveys

What is SNAP™?

- SNAP = Spectral Nondestructive Assay Platform
  - A point-kernel modeling routine
  - A product of *Pajarito Scientific Corporation*
- Analyzes gamma ray data from other vendor's detection systems (adaptable to what you already own)
- Detector intrinsic efficiency and angular response determined empirically with NIST traceable sources
- Quantifies any gamma emitting radiation source
  - Assay results include activity and concentration
  - Mass for SNM

SNAP™ Applications

- Developed in the 1990's primarily as a means to assay a huge variety of waste materials at LANL
- Additional features were added based on need
- Can also do laboratory measurement analyses on
  - Small samples
  - Holdup measurements
  - Area sources
- Not recommended for "infinite plane" area source (e.g., Fukushima)
- Not recommended for U or Pu samples whose thickness is beyond "infinite" for gammas

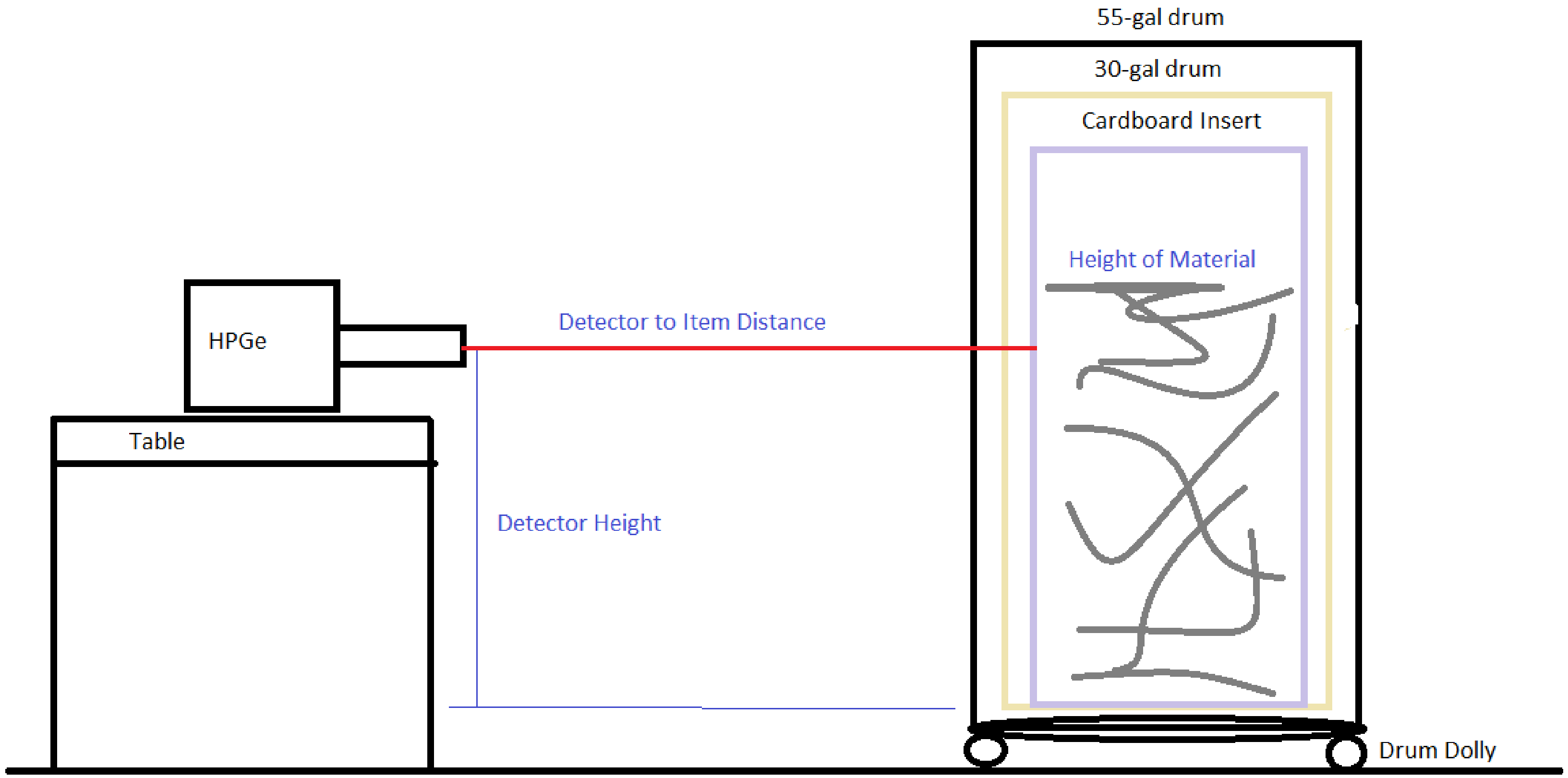
Quantifying Source Activity or Mass

$$Activity(Bq) = \frac{Net\ cps}{G \cdot EI \cdot Y \cdot SA}$$

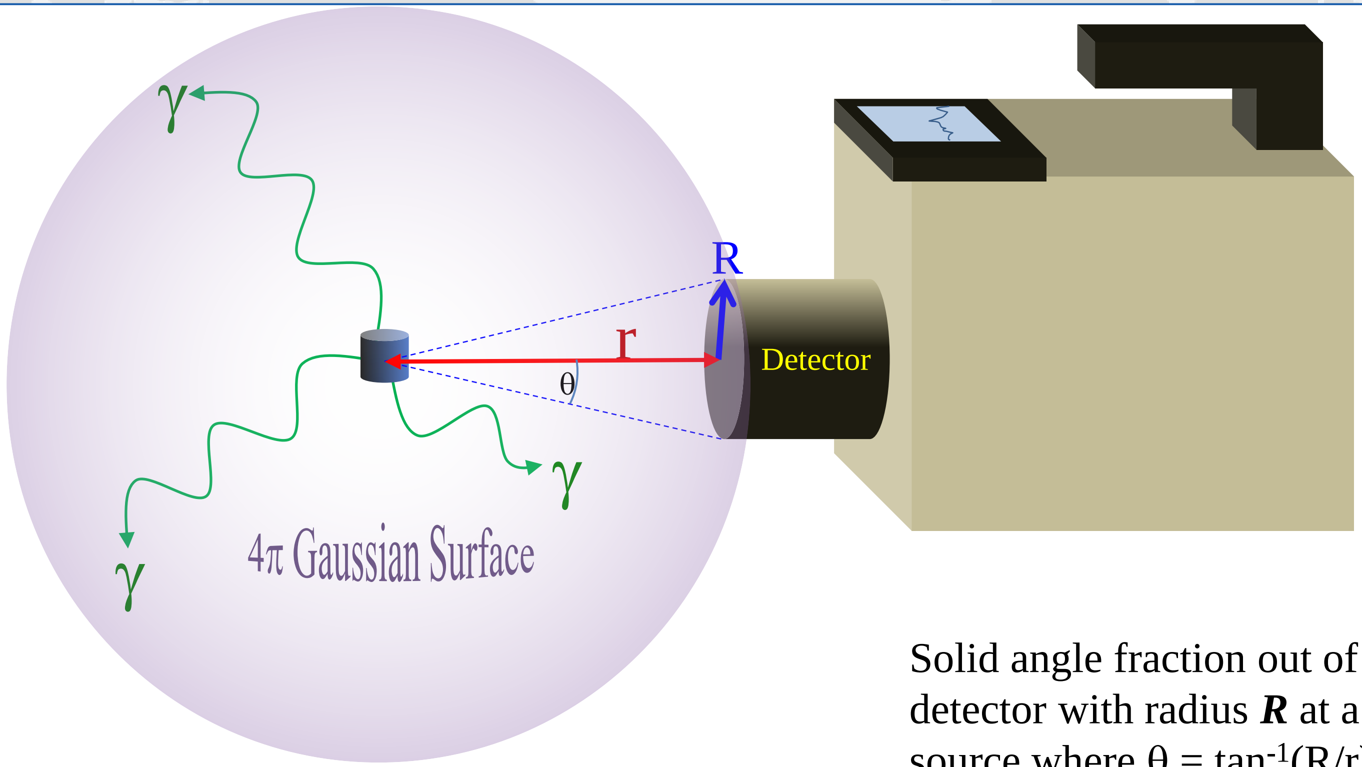
$$Mass(g) = Activity \cdot \frac{T_{1/2}}{ln2} \cdot \frac{A}{6.022E + 23}$$

G: geometry or solid angle correction for source-detector distance
E_I: intrinsic detection efficiency at that gamma ray energy
Y: yield (branching ratio) for specific gamma ray
SA: sources of attenuation (external shields and self absorption)
$T_{1/2}$: half life of the nuclide emitting that gamma ray
A: atomic mass of this nuclide

Typical Waste Drum Setup



Detector Solid Angle Fraction



Solid angle fraction out of 4π steradians for a detector with radius ***R*** at a distance ***r*** from the source where $\theta = \tan^{-1}(R/r)$:

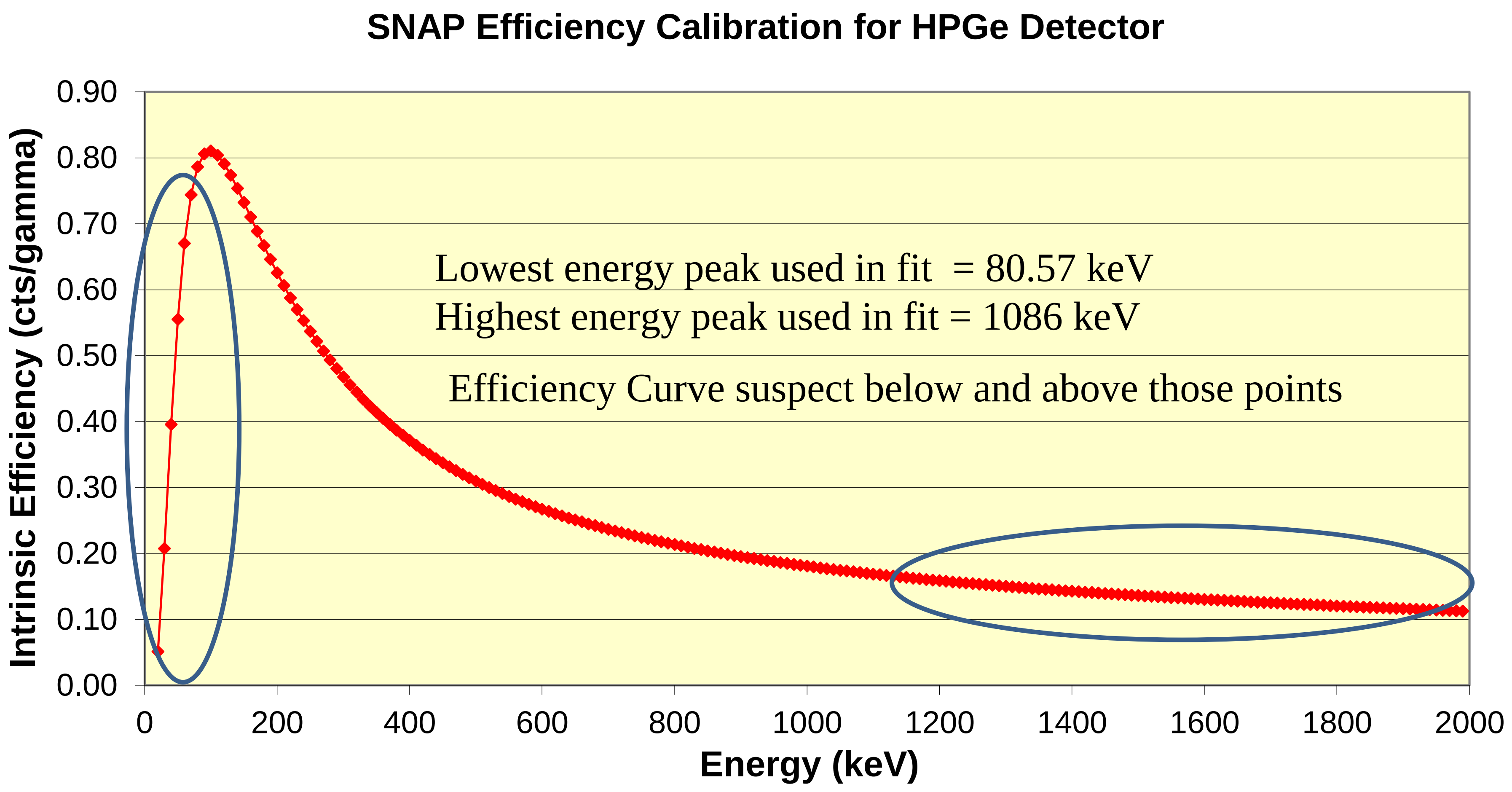
$$\frac{\Omega}{4\pi} = \frac{1}{2}(1 - \cos\theta)$$

Detection Efficiency

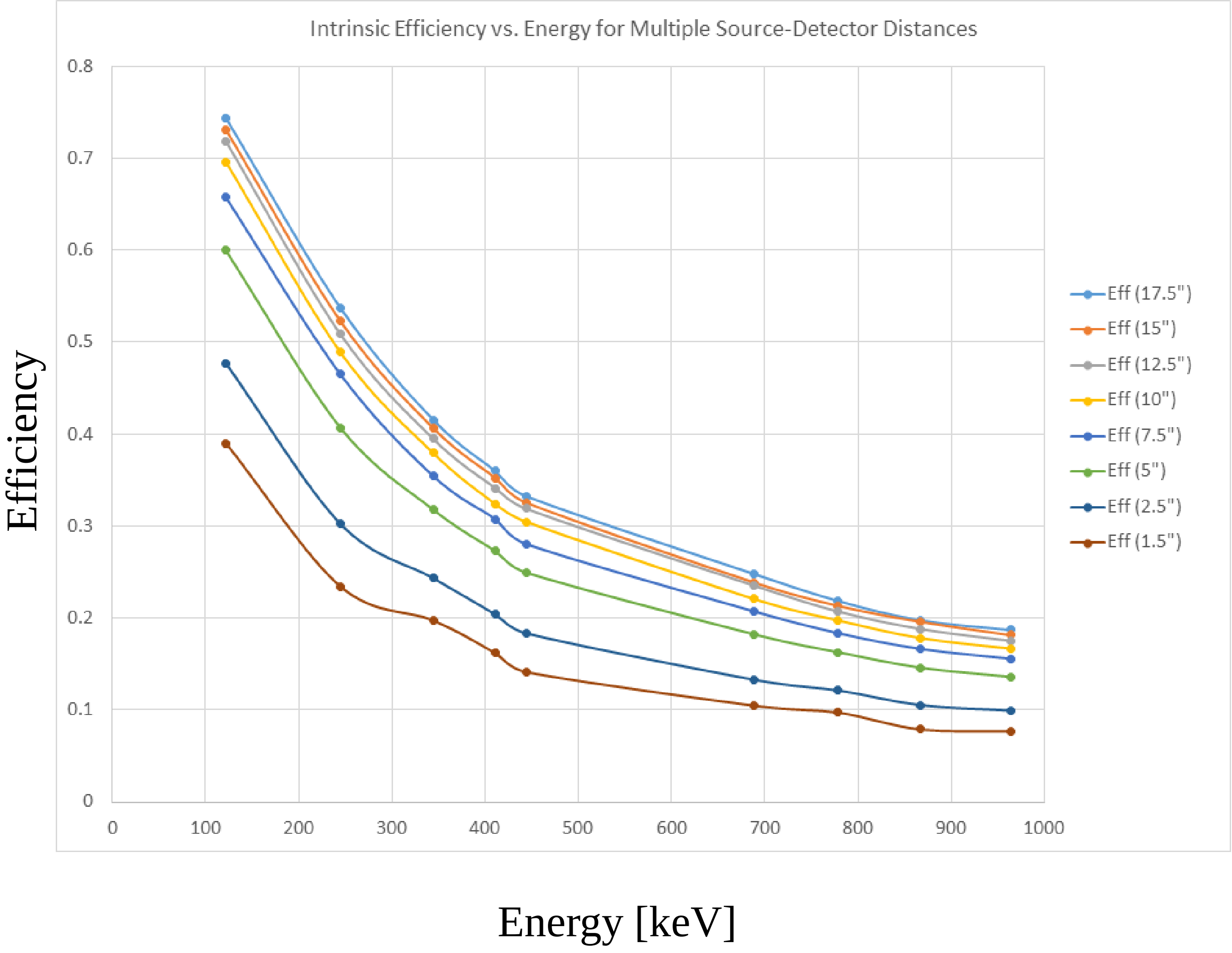
- SNAP uses the detector <u>intrinsic</u> efficiency (E_{I}) in calculations
- The intrinsic response is fairly constant over a large range of conditions (but not all)

$$\varepsilon_I = \frac{number\ of\ events\ recorded}{number\ of\ photons\ incident}$$

Typical Intrinsic Efficiency for HPGe Detector – limited range

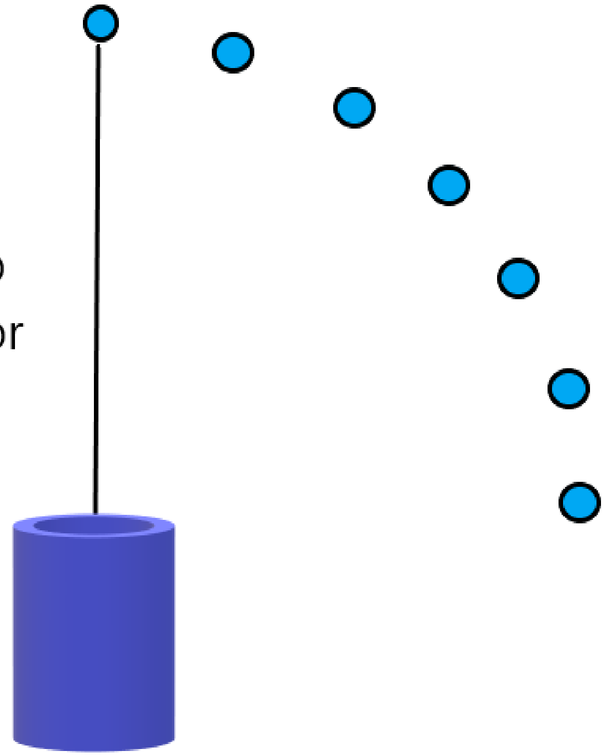


Intrinsic Efficiency Can Vary with Distance

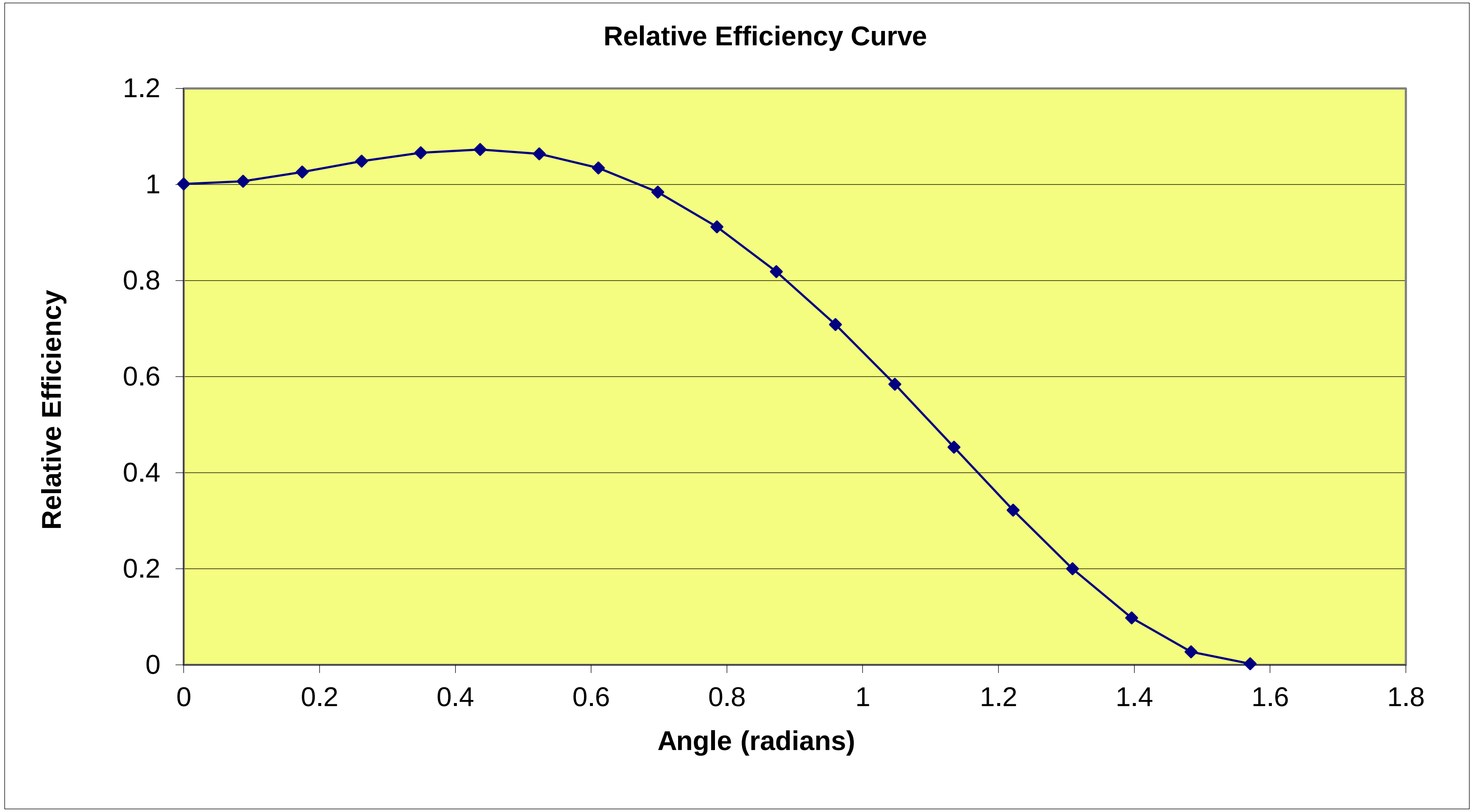


SNAP Corrects for Angular Response

9 measurements at 10 degree increments at 1 meter are taken to determine the angular response for offnormal source locations



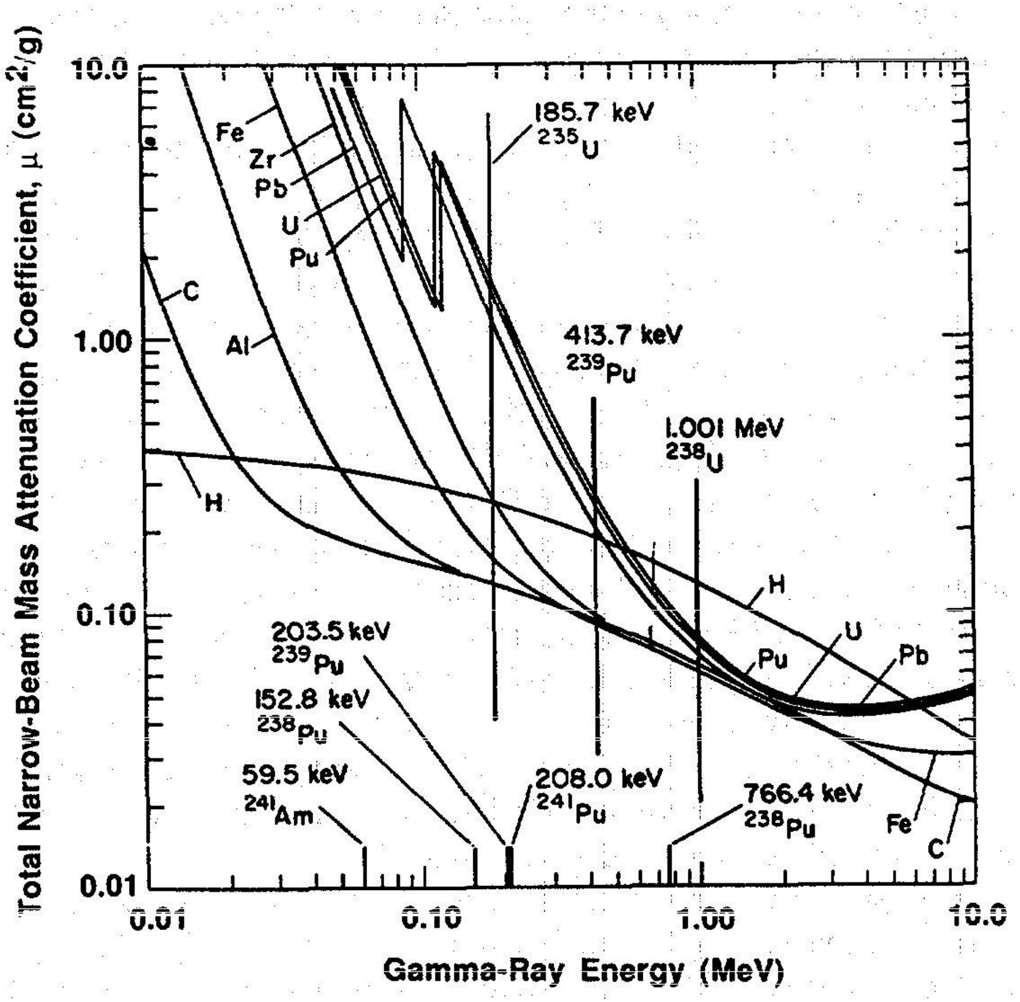
Collimated Detector: Efficiency as a Function of Transverse Angles



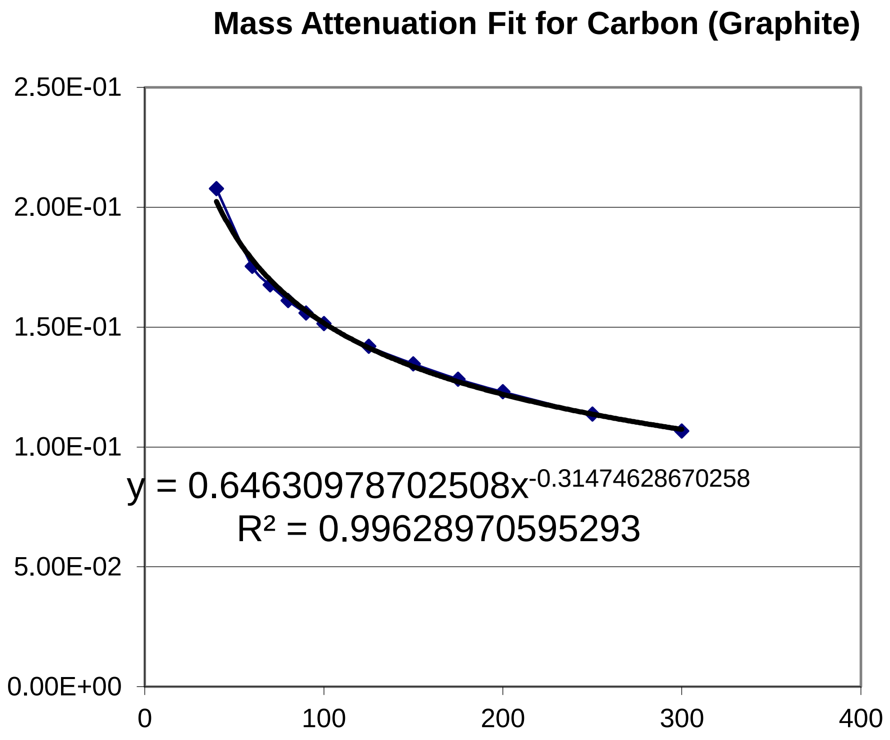
Attenuation Corrections in SNAP

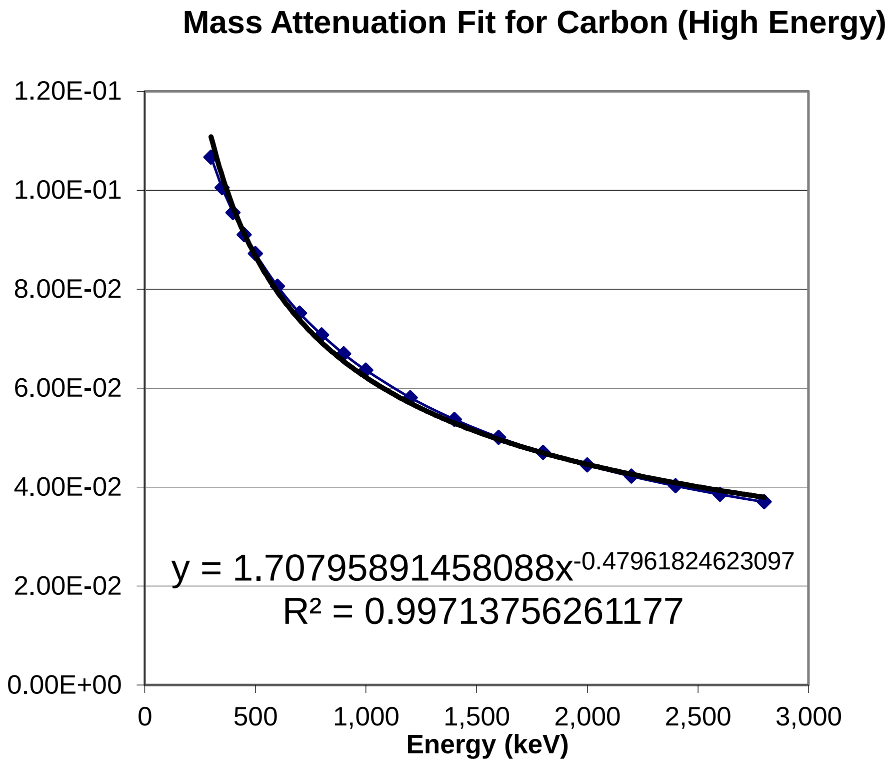
- Attenuation losses are a function of:
  - Materials in path of gammas
  - Inherent density of those materials
  - How the materials are dispersed in the volume of the sample container – thus, the effective density of the sample material
  - Energy of the gamma ray
- SNAP calculates Mass Attenuation Coefficients for each gamma ray used in the calculations

Shielding Materials and Energy Relationship

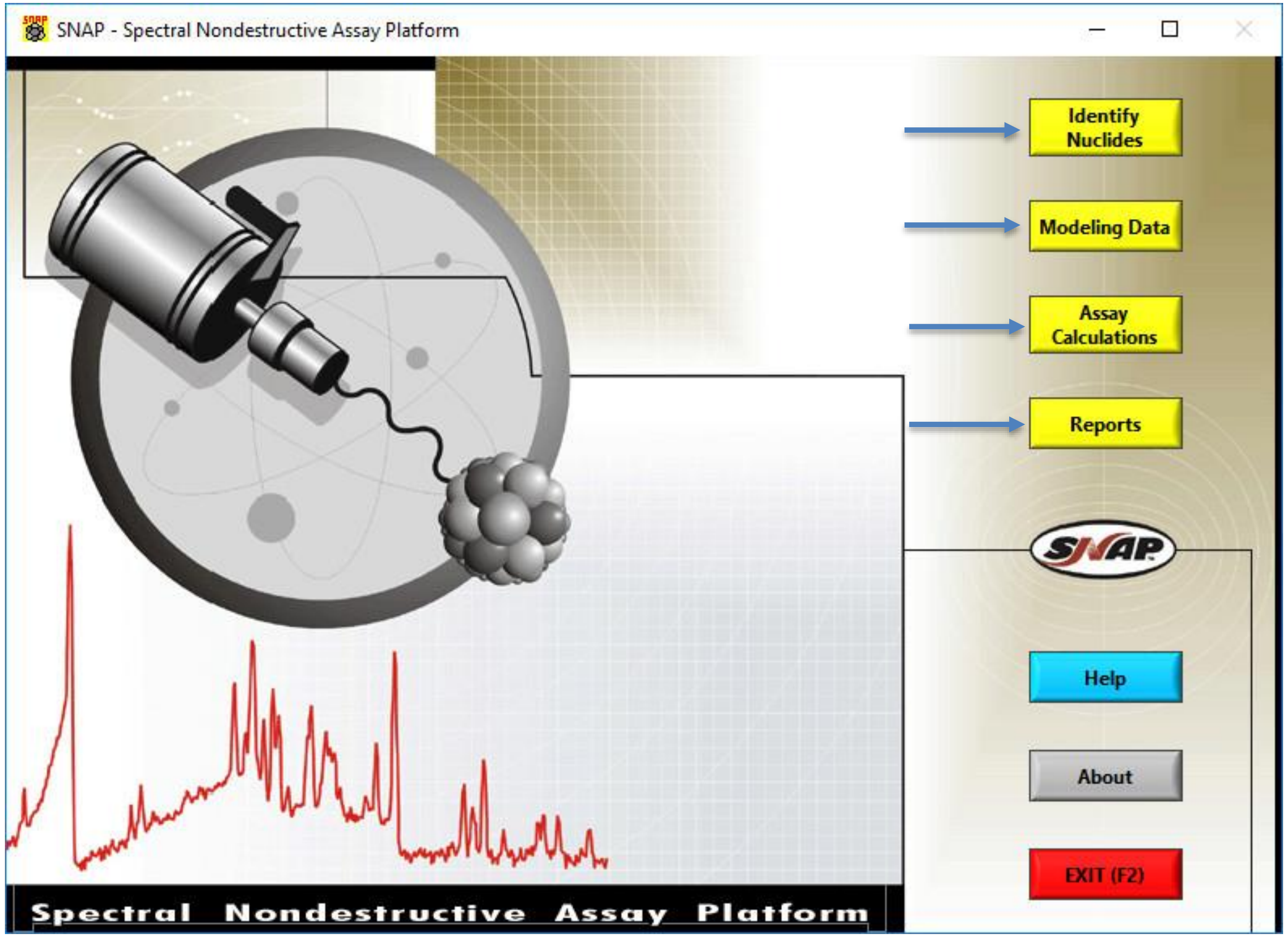


Example of Mass Attenuation Fits

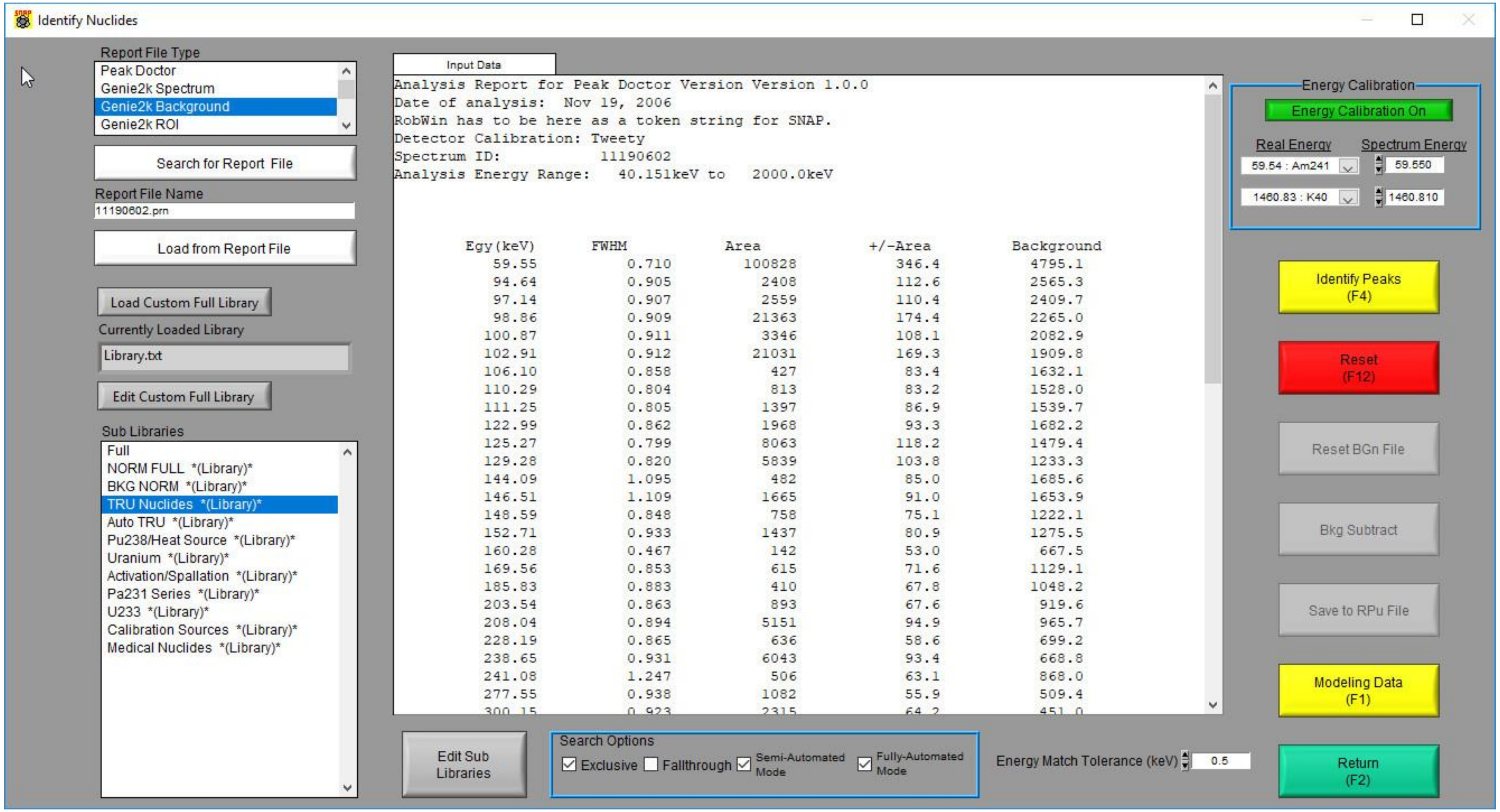




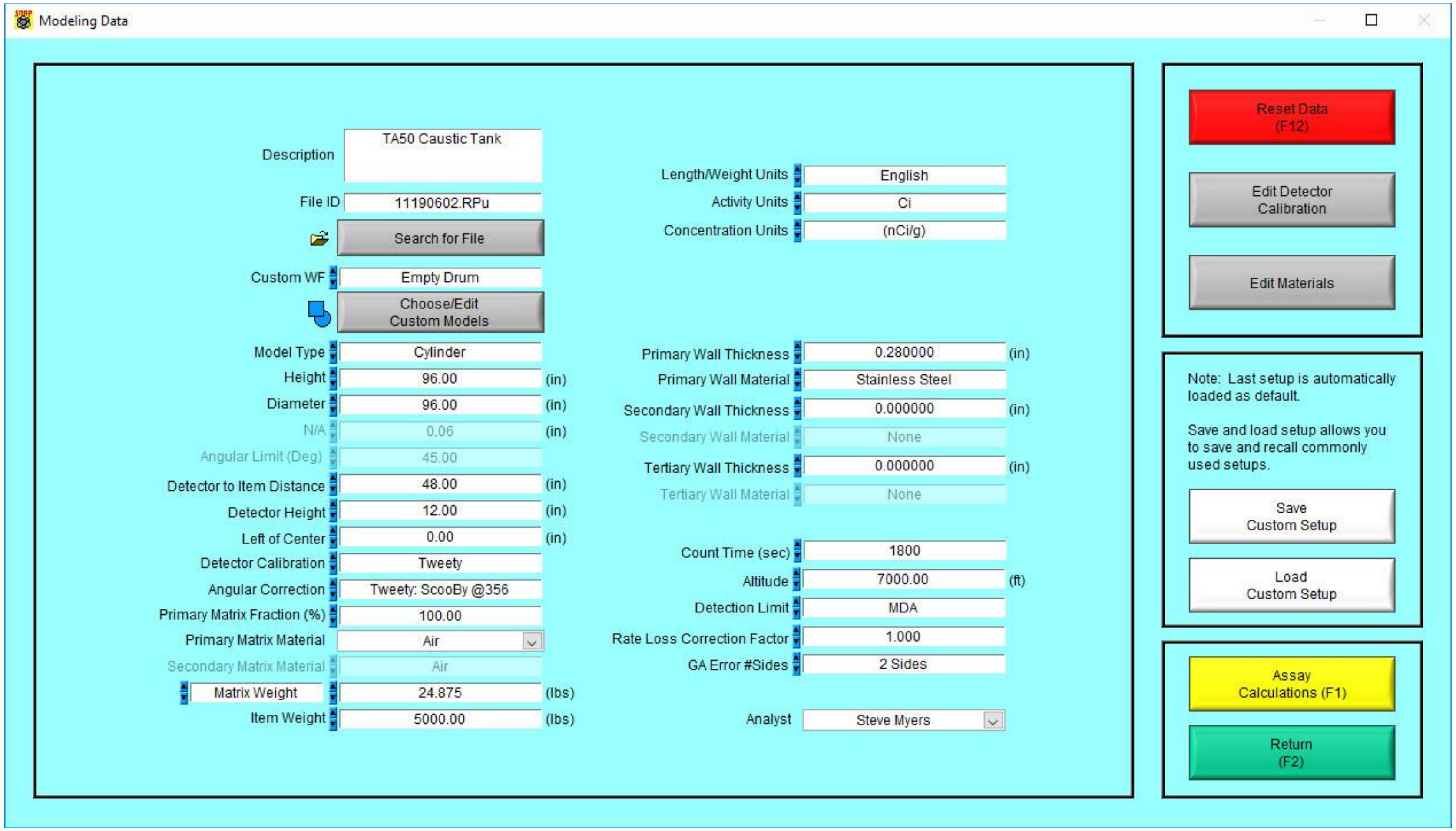
SNAP's 4 Step Process



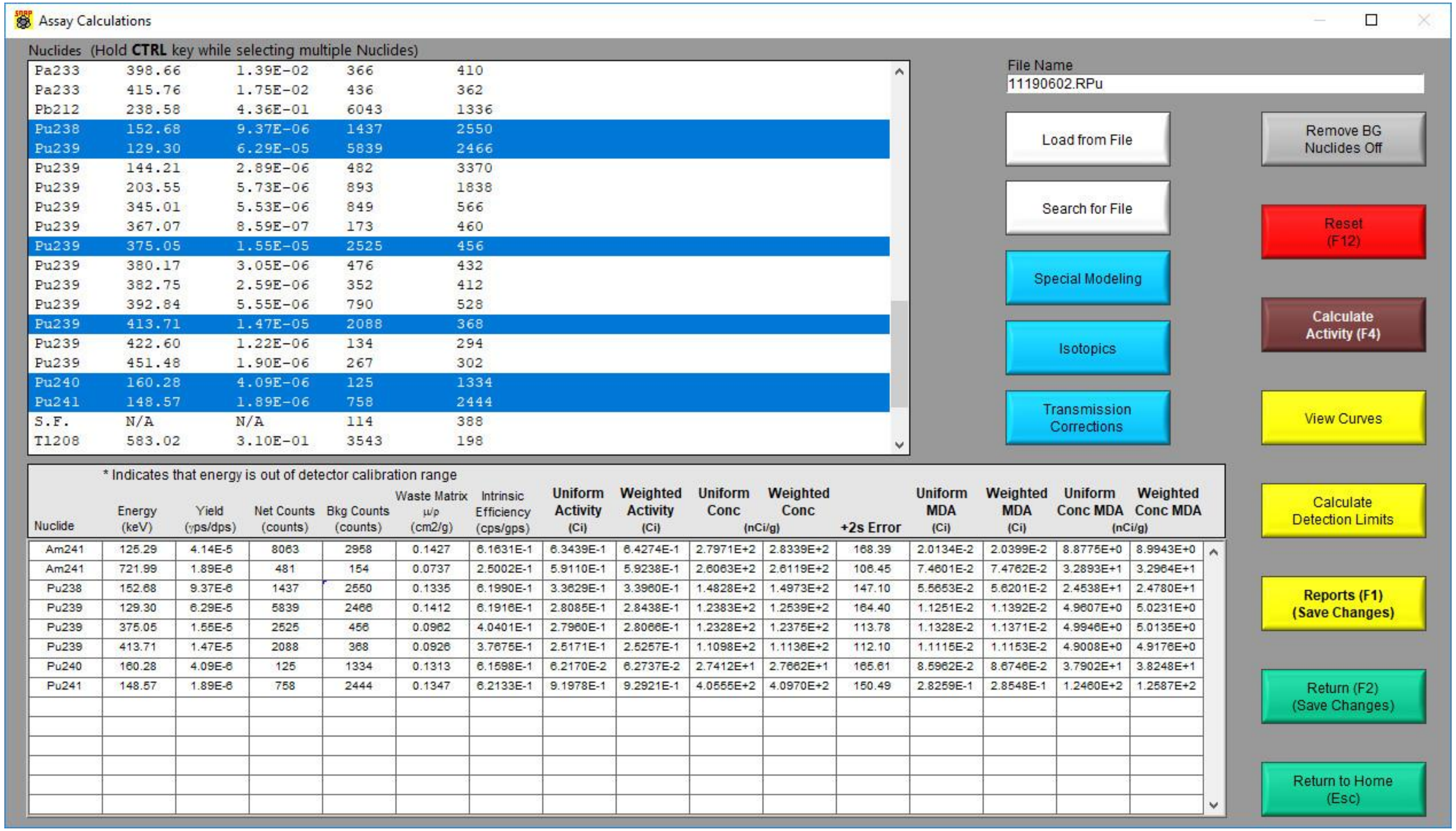
Process Step 1: Identify Nuclides (Library Driven)



Step 2: Enter Modeling Information



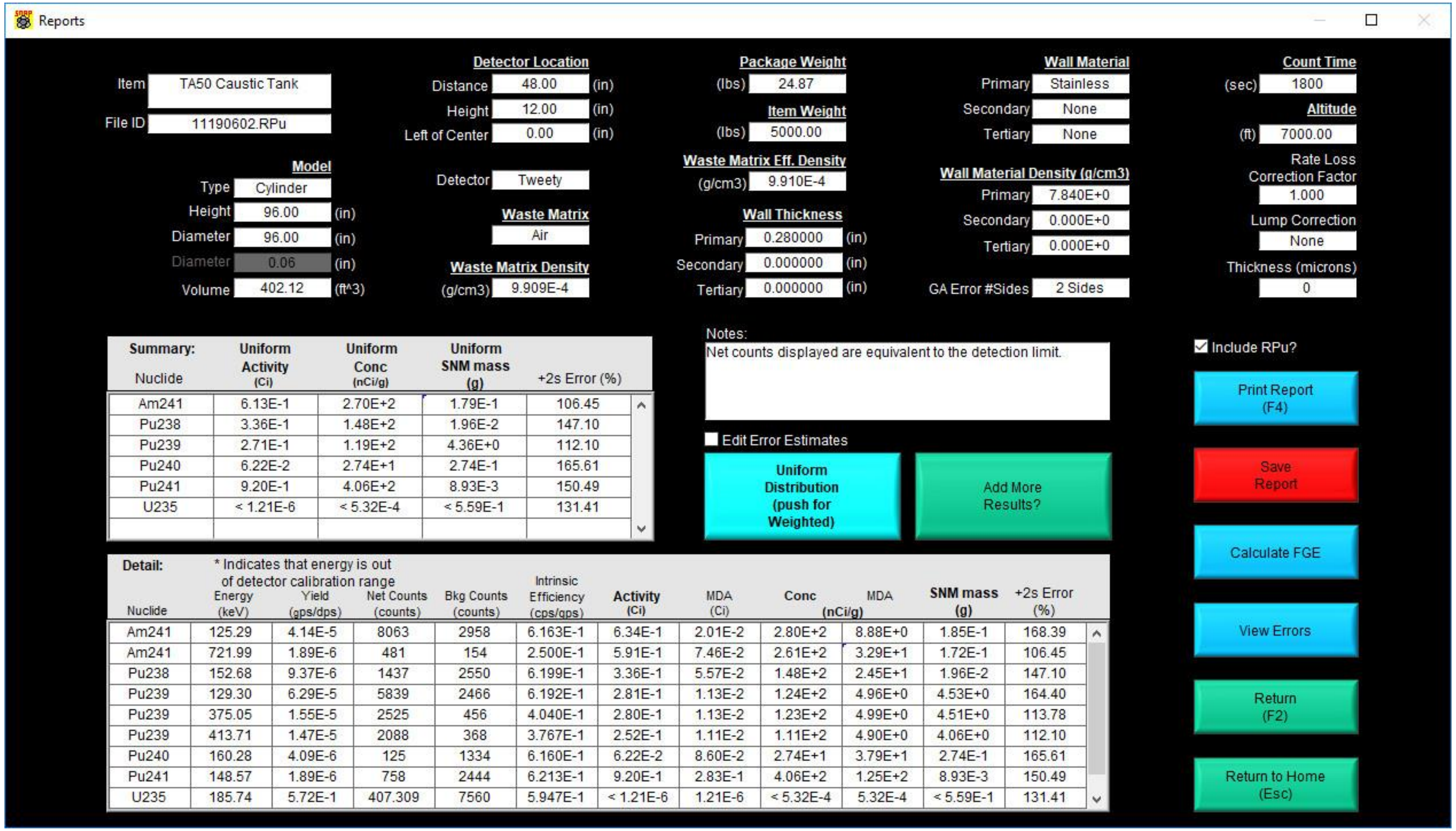
Step 3: Interactive Assay Calculations (user chooses peaks)



Pa233	398.66	1.39E-02	366	410
Pa233	415.76	1.75E-02	436	362
Pb212	238.58	4.36E-01	6043	1336
Pu238	152.68	9.37E-06	1437	2550
Pu239	129.30	6.29E-05	5839	2466
Pu239	144.21	2.89E-06	482	3370
Pu239	203.55	5.73E-06	893	1838
Pu239	345.01	5.53E-06	849	566
Pu239	367.07	8.59E-07	173	460
Pu239	375.05	1.55E-05	2525	456
Pu239	380.17	3.05E-06	476	432
Pu239	382.75	2.59E-06	352	412
Pu239	392.84	5.55E-06	790	528
Pu239	413.71	1.47E-05	2088	368
Pu239	422.60	1.22E-06	134	294
Pu239	451.48	1.90E-06	267	302
Pu240	160.28	4.09E-06	125	1334
Pu241	148.57	1.89E-06	758	2444
S.F.	N/A	N/A	114	388
Tl208	583.02	3.10E-01	3543	198

Nuclide	Energy (keV)	Yield (γps/dps)	Net Counts (counts)	Bkg Counts (counts)	Waste Matrix μ/ρ (cm2/g)	Intrinsic Efficiency (cps/gps)	Uniform Activity (Ci)	Weighted Activity (Ci)	Uniform Conc (nCi/g)	Weighted Conc (nCi/g)	+2s Error	Uniform MDA (Ci)	Weighted MDA (Ci)	Uniform Conc MDA (nCi/g)	Weighted Conc MDA (nCi/g)
Am241	125.29	4.14E-5	8063	2958	0.1427	6.1631E-1	6.3439E-1	6.4274E-1	2.7971E+2	2.8339E+2	168.39	2.0134E-2	2.0399E-2	8.8775E+0	8.9943E+0
Am241	721.99	1.89E-6	481	154	0.0737	2.5002E-1	5.9110E-1	5.9238E-1	2.6063E+2	2.6119E+2	106.45	7.4601E-2	7.4762E-2	3.2893E+1	3.2964E+1
Pu238	152.68	9.37E-6	1437	2550	0.1335	6.1990E-1	3.3629E-1	3.3960E-1	1.4828E+2	1.4973E+2	147.10	5.5653E-2	5.6201E-2	2.4538E+1	2.4780E+1
Pu239	129.30	6.29E-5	5839	2466	0.1412	6.1916E-1	2.8085E-1	2.8438E-1	1.2383E+2	1.2539E+2	164.40	1.1251E-2	1.1392E-2	4.9607E+0	5.0231E+0
Pu239	375.05	1.55E-5	2525	456	0.0962	4.0401E-1	2.7960E-1	2.8066E-1	1.2328E+2	1.2375E+2	113.78	1.1328E-2	1.1371E-2	4.9946E+0	5.0135E+0
Pu239	413.71	1.47E-5	2088	368	0.0926	3.7675E-1	2.5171E-1	2.5257E-1	1.1098E+2	1.1136E+2	112.10	1.1115E-2	1.1153E-2	4.9008E+0	4.9176E+0
Pu240	160.28	4.09E-6	125	1334	0.1313	6.1598E-1	6.2170E-2	6.2737E-2	2.7412E+1	2.7662E+1	165.61	8.5962E-2	8.6746E-2	3.7902E+1	3.8248E+1
Pu241	148.57	1.89E-6	758	2444	0.1347	6.2133E-1	9.1978E-1	9.2921E-1	4.0555E+2	4.0970E+2	150.49	2.8259E-1	2.8548E-1	1.2460E+2	1.2587E+2

Step 4: Finalize Reports



Reports

Item	TA50 Caustic Tank		
File ID	11190602.RPu		
Model			
Type	Cylinder		
Height	96.00	(in)	
Diameter	96.00	(in)	
Diameter	0.06	(in)	
Volume	402.12	(ft^3)	

Detector Location		
Distance	48.00	(in)
Height	12.00	(in)
Left of Center	0.00	(in)
Detector	Tweety	
Waste Matrix	Air	
Waste Matrix Density (g/cm3)	9.909E-4	

Package Weight (lbs)	24.87	
Item Weight (lbs)	5000.00	
Waste Matrix Eff. Density (g/cm3)	9.910E-4	
Wall Thickness		
Primary	0.280000	(in)
Secondary	0.000000	(in)
Tertiary	0.000000	(in)

Wall Material	
Primary	Stainless
Secondary	None
Tertiary	None
Wall Material Density (g/cm3)	
Primary	7.840E+0
Secondary	0.000E+0
Tertiary	0.000E+0
GA Error #Sides	2 Sides

Count Time (sec)	1800
Altitude (ft)	7000.00
Rate Loss Correction Factor	1.000
Lump Correction	None
Thickness (microns)	0

Summary: Nuclide	Uniform Activity (Ci)	Uniform Conc (nCi/g)	Uniform SNM mass (g)	+2s Error (%)
Am241	6.13E-1	2.70E+2	1.79E-1	106.45
Pu238	3.36E-1	1.48E+2	1.96E-2	147.10
Pu239	2.71E-1	1.19E+2	4.36E+0	112.10
Pu240	6.22E-2	2.74E+1	2.74E-1	165.61
Pu241	9.20E-1	4.06E+2	8.93E-3	150.49
U235	< 1.21E-6	< 5.32E-4	< 5.59E-1	131.41

Notes:
Net counts displayed are equivalent to the detection limit.

Edit Error Estimates

Uniform Distribution (push for Weighted)

Add More Results?

Include RPu?

Print Report (F4)

Save Report

Calculate FGE

View Errors

Return (F2)

Return to Home (Esc)

Detail: * Indicates that energy is out of detector calibration range

Nuclide	Energy (keV)	Yield (gps/dps)	Net Counts (counts)	Bkg Counts (counts)	Intrinsic Efficiency (cps/gps)	Activity (Ci)	MDA (Ci)	Conc (nCi/g)	MDA (nCi/g)	SNM mass (g)	+2s Error (%)
Am241	125.29	4.14E-5	8063	2958	6.163E-1	6.34E-1	2.01E-2	2.80E+2	8.88E+0	1.85E-1	168.39
Am241	721.99	1.89E-6	481	154	2.500E-1	5.91E-1	7.46E-2	2.61E+2	3.29E+1	1.72E-1	106.45
Pu238	152.68	9.37E-6	1437	2550	6.199E-1	3.36E-1	5.57E-2	1.48E+2	2.45E+1	1.96E-2	147.10
Pu239	129.30	6.29E-5	5839	2466	6.192E-1	2.81E-1	1.13E-2	1.24E+2	4.96E+0	4.53E+0	164.40
Pu239	375.05	1.55E-5	2525	456	4.040E-1	2.80E-1	1.13E-2	1.23E+2	4.99E+0	4.51E+0	113.78
Pu239	413.71	1.47E-5	2088	368	3.767E-1	2.52E-1	1.11E-2	1.11E+2	4.90E+0	4.06E+0	112.10
Pu240	160.28	4.09E-6	125	1334	6.160E-1	6.22E-2	8.60E-2	2.74E+1	3.79E+1	2.74E-1	165.61
Pu241	148.57	1.89E-6	758	2444	6.213E-1	9.20E-1	2.83E-1	4.06E+2	1.25E+2	8.93E-3	150.49
U235	185.74	5.72E-1	407.309	7560	5.947E-1	< 1.21E-6	1.21E-6	< 5.32E-4	5.32E-4	< 5.59E-1	131.41

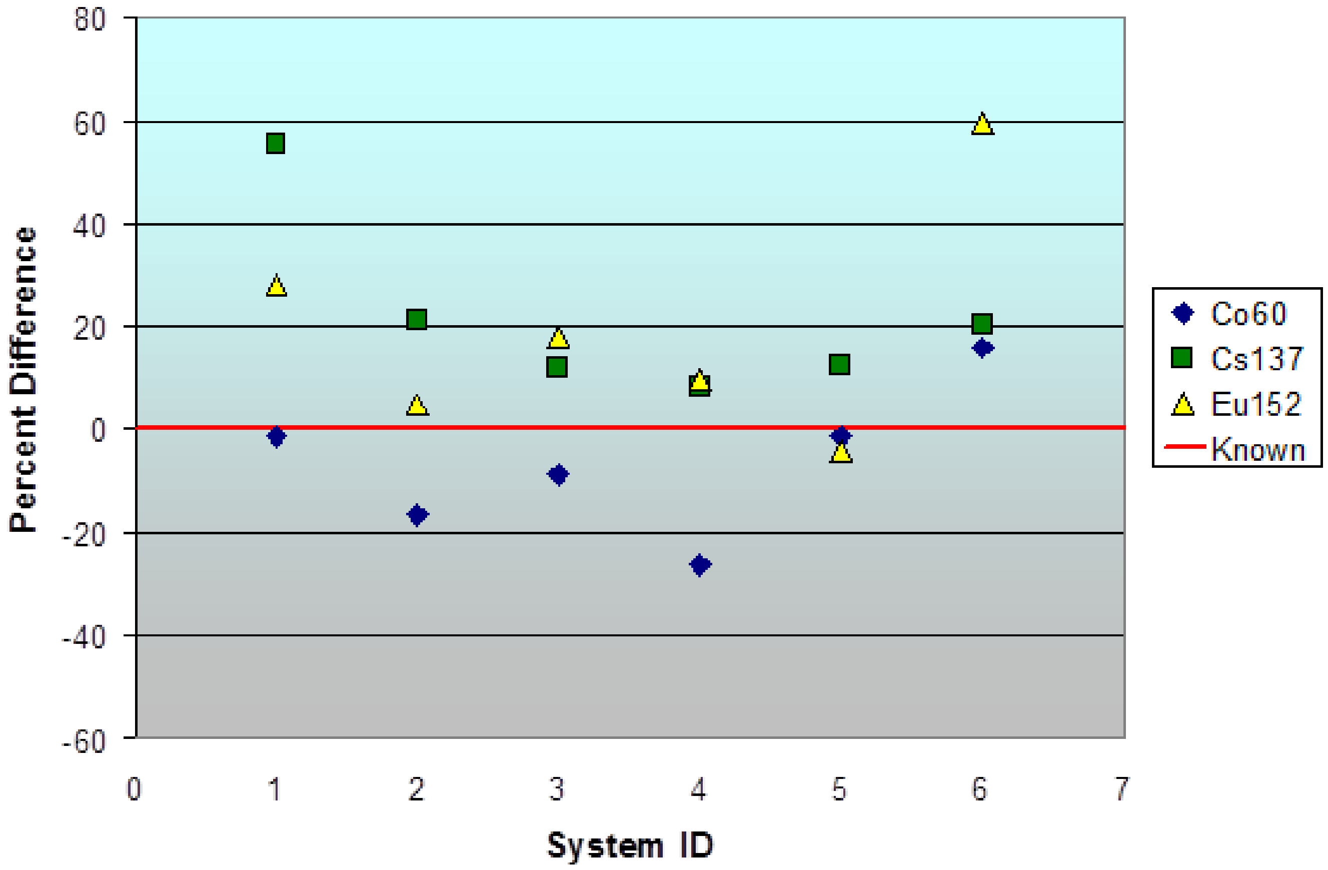
Verification Results: PDP Challenge

Performance Demonstration Project Drums with various matrices used to certify WIPP assay systems

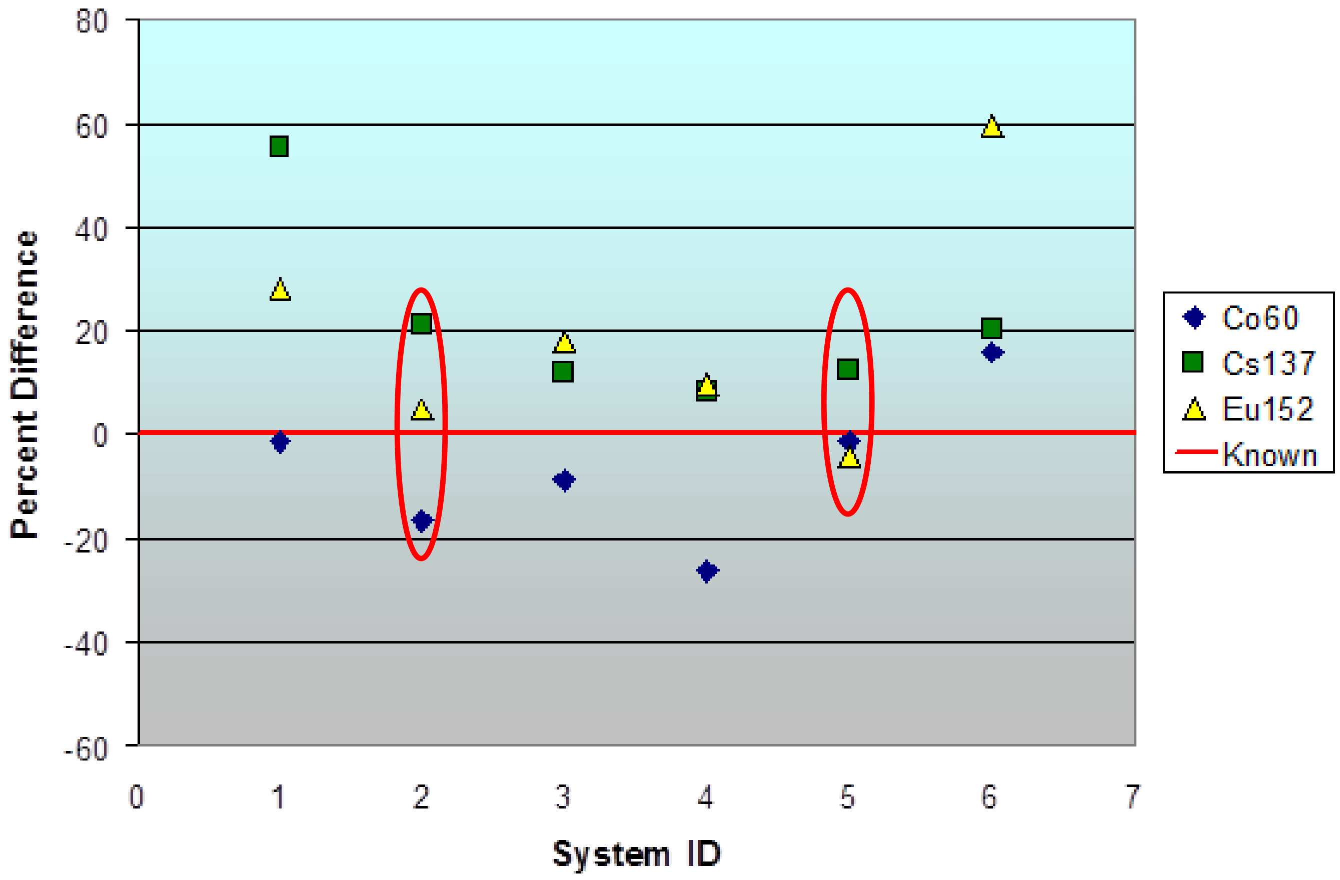
Point sources included Co60, Cs137, and Eu152

Matrix Materials included shredded paper and mixed metals

Results of Six Participants



Results of Six Participants
LANL SNAP Systems Circled in Red



More Verification Results

Pu Disc	Detector	Mass of Pu239 (g)	SNAP Result (g)	% Difference
Pu Disc	Tweety	108	110.4	2.22%

U-233 Metals	Detector	Mass of U233 (g)	SNAP Result (g)	% Difference
Metal Piece 1	Roadrunner	107	100.0	-6.54%
Metal Piece 2	Roadrunner	72	74.3	3.19%

Pu-238 Rods	Detector	Certified Mass of Pu238 (g)	SNAP Result (g)	% Difference
STDSGPUL	Tweety	0.0952	0.1012	6.32%
	Mickey	0.0952	0.098	2.96%
	Sylvester	0.0952	0.0912	-4.20%
	Roadrunner	0.0952	0.0932	-2.10%
STDSGPUH	Bullwinkle	0.5564	0.5878	5.64%

HEU Fuel Rods	Gross Weight of Rods (kg)	Certified Mass of U235 (g)	SNAP Result (g)	% Difference
Lot 092	19.13	354.01	367	3.67%
Lot 097	21.08	106.13	109	2.70%
Lot 098	20.39	81.98	78	-4.80%
Lot 099	6.12	129.74	129	-0.59%

Uranium Drum Verification Results

HEU Standards in 55 Gal Drums	Detector	Certified Mass of U235 (g)	SNAP Result (g)	% Difference
STDSGUD1	Tweety	31.20	28.06	-10.06%
	Mickey	31.20	30.98	-0.70%
	Bullwinkle	31.20	30.50	-2.24%
	Sylvester	31.20	32.13	2.98%
	Roadrunner	31.20	27.98	-10.32%
STDSGUD2	Tweety	100.99	94.26	-6.66%
	Mickey	100.99	101.22	0.23%
	Bullwinkle	100.99	101.58	0.59%
	Sylvester	100.99	96.60	-4.35%
	Roadrunner	100.99	107.40	6.35%

There were many others – mostly in waste drums

Summary

- All necessary corrections are carefully performed to allow for very good assay results of materials that are otherwise "not amenable to measurement" by traditional assay systems
- Several HPGe systems are certified to perform safeguards measurements at LANL
- MDA's can be determined and a Special Modeling capability extends the potential use to many unique challenges